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NASA-CR-171666

e. 1

COLUMBIA: THE FIRST FIVE FLIGHTS

ENTRY HEATING DATA SERIES

VOLUME 4

THE LOWER WINDWARD WING 50% AND 80% SEMI-SPANS

By S. D. Williams

May 1983

(NASA-CR-171666) COLUMBIA: THE FIRST FIVE FLIGHTS ENTRY HEATING DATA SERIES. VOLUME 4: THE LOWER WINDWARD WING 50 PERCENT AND 80 PERCENT SEMISPANS Final Report (Lockheed Engineering and Management) 515 p G3/16 N83-32838 Unclas 36029

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Johnson Space Center
Houston, Texas

ERRATA

Columbia: The First Five Flights
Entry Heating Data Series
Volume 4
The Lower Windward Wing 50% and 80% Semi-Spans
May 1983
NASA-CR-171666

After publication and distribution of the document listed above it was observed that the numerical values of the Normal Shock Reynolds Numbers flagged on the h/h_{ref} vs. α plots were incorrectly labeled. Although the flagged values were correct with respect to time and α the freestream values instead of the normal shock values were printed. The analyst can obtain the correct value for wind tunnel conditions by multiplying the stated values by 0.1121 or by using the values shown in the following table. This error is consistent for Volumes 2 through 6. The author regrets any inconvenience this has caused for the serious researcher.

Correlation Between Free Stream and Normal Shock
Reynolds Numbers at Wind Tunnel Conditions

0.0175 Scale Re_∞ /ft X 10^6	107 Ft. Length Re_∞ X 10^6	107 Ft. Length Re_{NS} X 10^5
0.50	0.936	1.050
1.00	1.873	2.099
1.50	2.809	3.149
2.00	3.745	4.198
2.50	4.681	5.248
3.00	5.618	6.297
3.50	6.554	7.347
3.70	6.928	7.767

SDW

DISCUSSION:

Over 2,000 design flight instruments (DFI) were installed on Columbia with the majority of the DFI flight data recorded during ascent and entry (Ref. 1). Additional real-time instrumentation was used to continuously monitor the thermal subsystems during each flight. Successful completion of the first five flights of the Space Shuttle Orbiter has provided sufficient data from radiometers, thermocouples, and pressure transducers to appraise the aerothermodynamic/TPS performance.

The entry heating presented in this report is restricted to the Lower Wingward Wing 50% and 80% Semi-Spans, see Fig. 1. A tabulation of the orbiter X, Y, Z coordinates for each instrument can be found in Table I. This data is presented in two Appendices:

Appendix A: Correlation Parameters
Appendix B: Flight Data

As an aid to the reader, the page numbers for the specific correlation parameters and flight data for each Appendix can be found in Tables II and III.

The surface heating and temperature data presented in this volume is based on the thermal analysis at each individual location via the JSC NONLIN/INVERSE computer program, Ref. 2. Values of angle-of-attack and the derived free stream Mach number were obtained from the JSC/MPAD Best Estimated Trajectory (BET) data tapes for each flight. The corresponding data values for Normal Shock Reynolds number (Ref. 3), reference heating rate, reference film coefficient, and total enthalpy were obtained via the MINIVER computer program (Ref. 4). Values of h/h_{ref} were computed using $0.9H_T$ recovery enthalpy.The comparison of wind tunnel data ($0.9H_T$) with flight data was obtained by linear interpolation for all locations except for the 50% semi-span X/C=0.40 location. At wind tunnel conditions, Mach$\sim$8, (Ref. 5) the Normal Shock Reynolds number is .1121 times the Reynolds number based on freestream parameters.

All heating rates were calculated with a view factor of 1. The surface emissivity of all instruments was assumed to be 0.85. All heating rates compared to flight parameters (α, M_∞, and Re_{NS}) are presented on a log scale with imposed limits of $10^{-3} \leq h/h_{ref} \leq 1$. No wind tunnel data is presented for those instruments on the elevons since the elevon deflection varied during entry. As an aid for interpreting this data flag events are superimposed on the plots. For the α vs. h/h_{ref} plots the values of Re_{NS} corresponding to wind tunnel data values are denoted. For the M_∞ vs. h/h_{ref} and Re_{NS} vs. h/h_{ref} plots values of α (latest in time occurrence) are denoted.

The DFI data is available throughout the entire trajectory for STS-2, STS-3, and STS-5. Due to DFI data recorder errors or malfunctions only limited entry data is available for STS-1 and STS-4.

Entry heating data for other vehicle areas is presented in additional volumes. Volume 1: An Overview, see Ref. 6, contains the underlying assumptions, detailed trajectory information, and pertinent information for the integration of all subsequent volumes. In order to provide an adequate overview of the entry heating volume 1 will be the last released publication in this series of reports.

REFERENCES:

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2. Williams, S. D. and Curry, D. M., An Analytical and Experimental Study Using a Single Embedded Thermocouple, J. Spacecraft and Rockets, Vol. 14, October 1977, pp. 632-637.

3. Ried, R. C., Jr.; Goodrich, W. D.; Strouhal, G.; and Curry, D. M.: The Importance of Boundary Layer Transition to the Space Shuttle Design, Proceedings of the Boundary Layer Transition Workshop held Nov. 3-5, 1971. Aerospace Report No. TOR-0172 (S2816-16) -5, Dec. 20, 1971.

4. Hender, D. R., A Miniature Version of the JA70 Aerodynamic Heating Computer Program, H800 (MINIVER) MDC G0462, McDonnell Douglas Astonautics Company Huntington Beach, CA, June 1970, Revised January 1972.

5. Martindale, W. R., Kaul, C. E., and Nutt, K. W., Test Results from the NASA/ Rockwell International Space Shuttle Orbiter Heating Test (OH39B) conducted in the AEDC-VKF Tunnel B, AEDC-DR-75-17 VonKarman Gas Dynamics Facility, ARO, Inc., Arnold Engineering Development Center, Arnold Air Force Station, Tennessee, Feb. 28, 1975.

6. Williams, S. D. Columbia: The First Five Flights Entry Heating Data Series, Volume 1, An Overview

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WINDWARD LOWER SURFACE

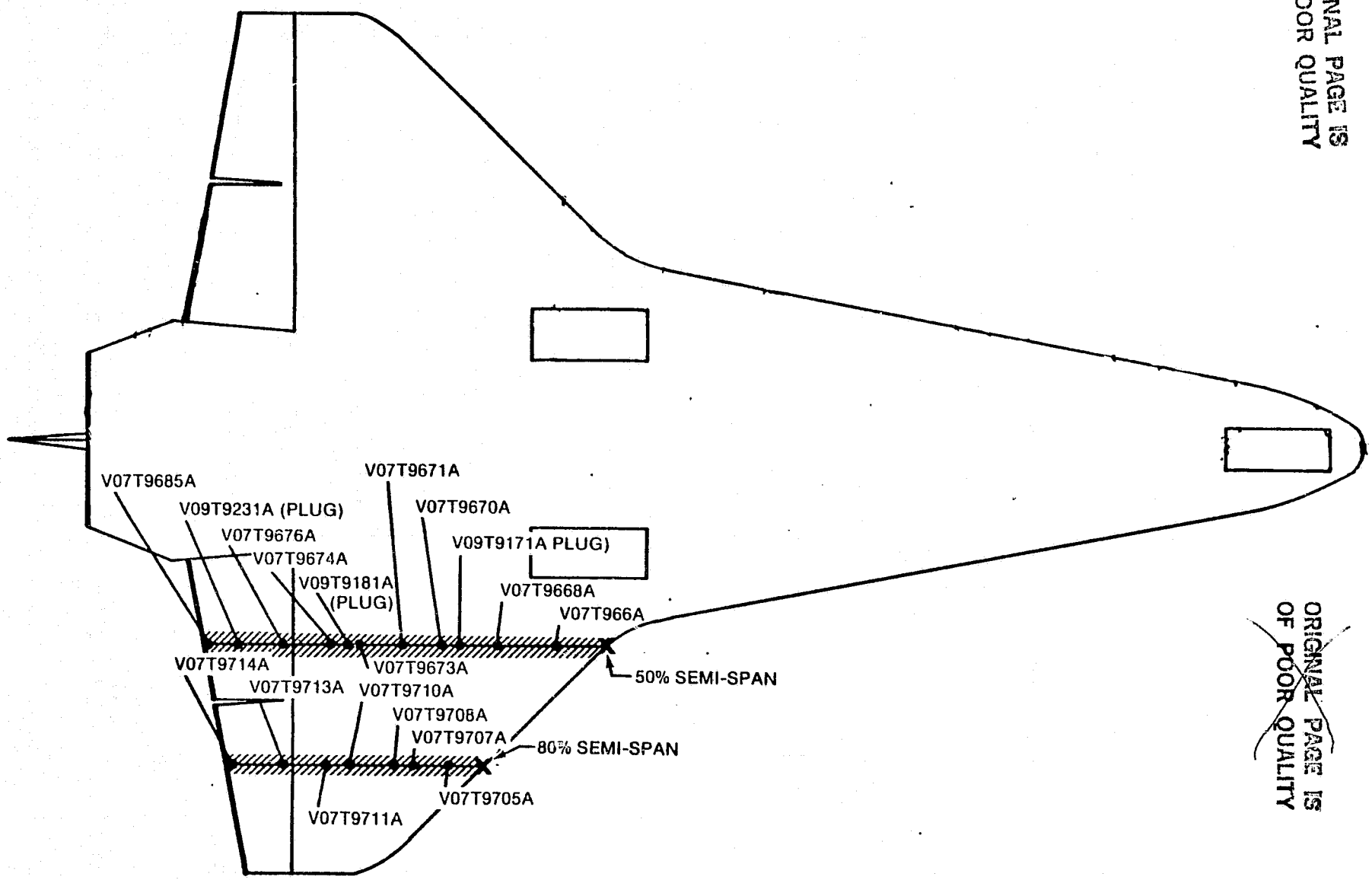

Figure 1 - Measurement Location on Wing Lower Surface

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TABLE I

LOWER WING 50% AND 80% SEMI-SPAN COORDINATES

50% SEMI-SPAN Yo = -234.170

MID	X/C	Xo	Yo
V07T9666A	0.13	1121.7	-235.5
9668A	0.28	1183.2	-233.4
V09T9171A+	0.36	1219.1	-239.5
V07T9670A	0.40	1235.4	-233.3
9671A	0.50	1275.7	-235.5
9673A	0.61	1320.2	-233.3
V09T9181A+	0.64	1335.9	-239.9
V07T9674A	0.68	1353.1	-236.4
9676A	0.79	1397.7	-234.0
V09T9231A+	0.90	1443.5	-231.4
V07T9685A	0.99	1477.7	-240.2
Eleven Hinge	0.76	1386	

80% SEMI-SPAN Yo = -374.672

MID	X/C	Xo	Yo
V07T9705A	0.15	1248.0	-368.5
9707A	0.28	1280.4	-367.9
9708A	0.35	1297.1	-370.8
9710A	0.52	1340.3	-368.3
9711A	0.61	1362.0	-369.3
9713A	0.77	1402.0	-373.6
9714A	0.98	1454.3	-372.3
Elevon Hinge	0.71	1386	

+ Plug instrumented

TABLE II

PAGE NUMBERS FOR APPENDIX A:

CORRELATION PARAMETERS

Flight Parameter			STS-1	STS-2	STS-3	STS-4	STS-5
			STS - Flight				
α	vs	t	1	2	3	4	5
M_∞	vs	t	6	7	8	9	10
Re_{NS}	vs	t	11	12	13	14	15
α	vs	M_∞	16	17	18	19	20
α	vs	Re_{NS}	21	22	23	24	25
M_∞	vs	Re_{NS}	26	27	28	29	30
$\dot{q}_{ref}$	vs	t	31	32	33	34	35
$\dot{q}_{ref}$	vs	α	36	37	38	39	40
$\dot{q}_{ref}$	vs	M_∞	41	42	43	44	45
$\dot{q}_{ref}$	vs	Re_{NS}	46	47	48	49	50
h_{ref}	vs	t	51	52	53	54	55
h_{ref}	vs	α	56	57	58	59	60
h_{ref}	vs	M_∞	61	62	63	64	65
h_{ref}	vs	Re_{NS}	66	67	68	69	70

Table III - Page Numbers for Appendix B: Flight Data

Measurement				STS - Flight				
				STS-1	STS-2	STS-3	STS-4	STS-5
V07T9666A	- h/h_{ref}	vs	α	1	2	3	4	5
	- h/h_{ref}	vs	M_∞	6	7	8	9	10
	- h/h_{ref}	vs	Re_{NS}	11	12	13	14	15
	- $\dot{q}_{conv}$	vs	t	16	17	18	19	20
	- T_s	vs	t	21	22	23	24	25
V07T9668A	- h/h_{ref}	vs	α	26	27	28	29	30
	- h/h_{ref}	vs	M_∞	31	32	33	34	35
	- h/h_{ref}	vs	Re_{NS}	36	37	38	39	40
	- $\dot{q}_{conv}$	vs	t	41	42	43	44	45
	- T_s	vs	t	46	47	48	49	50
V09T9171A	- h/h_{ref}	vs	α	51	52	53	54	55
	- h/h_{ref}	vs	M_∞	56	57	58	59	60
	- h/h_{ref}	vs	Re_{NS}	61	62	63	64	65
	- $\dot{q}_{conv}$	vs	t	66	67	68	69	70
	- T_s	vs	t	71	72	73	74	75
V07T9670A	- h/h_{ref}	vs	α	76	77	78	79	80
	- h/h_{ref}	vs	M_∞	81	82	83	84	85
	- h/h_{ref}	vs	Re_{NS}	86	87	88	89	90
	- $\dot{q}_{conv}$	vs	t	91	92	93	94	95
	- T_s	vs	t	96	97	98	99	100
V07T9671A	- h/h_{ref}	vs	α	101	102	103	104	105
	- h/h_{ref}	vs	M_∞	106	107	108	109	110
	- h/h_{ref}	vs	Re_{NS}	111	112	113	114	115
	- $\dot{q}_{conv}$	vs	t	116	117	118	119	120
	- T_s	vs	t	121	122	123	124	125
V07T9673A	- h/h_{ref}	vs	α	126	127	128	129	130
	- h/h_{ref}	vs	M_∞	131	132	133	134	135
	- h/h_{ref}	vs	Re_{NS}	136	137	138	139	140
	- $\dot{q}_{conv}$	vs	t	141	142	143	144	145
	- T_s	vs	t	146	147	148	149	150

Table III - Continued

Measurement				STS - Flight				
				STS-1	STS-2	STS-3	STS-4	STS-5
V09T9181A	- h/h_{ref}	vs	α	151	152	153	154	155
	- h/h_{ref}	vs	M_∞	156	157	158	159	160
	- h/h_{ref}	vs	Re_{NS}	161	162	163	164	165
	- $\dot{q}_{conv}$	vs	t	166	167	168	169	170
	- T_s	vs	t	171	172	173	174	175
V07T9674A	- h/h_{ref}	vs	α	176	177	178	179	180
	- h/h_{ref}	vs	M_∞	181	182	183	184	185
	- h/h_{ref}	vs	Re_{NS}	186	187	188	189	190
	- $\dot{q}_{conv}$	vs	t	191	192	193	194	195
	- T_s	vs	t	196	197	198	199	200
V07T9676A	- h/h_{ref}	vs	α	201	202	203	204	205*
	- h/h_{ref}	vs	M_∞	206	207	208	209	210*
	- h/h_{ref}	vs	Re_{NS}	211	212	213	214	215*
	- $\dot{q}_{conv}$	vs	t	216	217	218	219	220*
	- T_s	vs	t	221	222	223	224	225*
V09T9231A	- h/h_{ref}	vs	α	226	227	228	229	230
	- h/h_{ref}	vs	M_∞	231	232	233	234	235
	- h/h_{ref}	vs	Re_{NS}	236	237	238	239	240
	- $\dot{q}_{conv}$	vs	t	241	242	243	244	245
	- T_s	vs	t	246	247	248	249	250
V07T9685A	- h/h_{ref}	vs	α	251	252	253	254	255
	- h/h_{ref}	vs	M_∞	256	257	258	259	260
	- h/h_{ref}	vs	Re_{NS}	261	262	263	264	265
	- $\dot{q}_{conv}$	vs	t	266	267	268	269	270
	- T_s	vs	t	271	272	273	274	275
V07T9705A	- h/h_{ref}	vs	α	276	277	n/a	278	279
	- h/h_{ref}	vs	M_∞	280	281	n/a	282	283
	- h/h_{ref}	vs	Re_{NS}	284	285	n/a	286	287
	- $\dot{q}_{conv}$	vs	t	288	289	n/a	290	291
	- T_s	vs	t	292	293	n/a	294	295

*Flight Data may be in error.

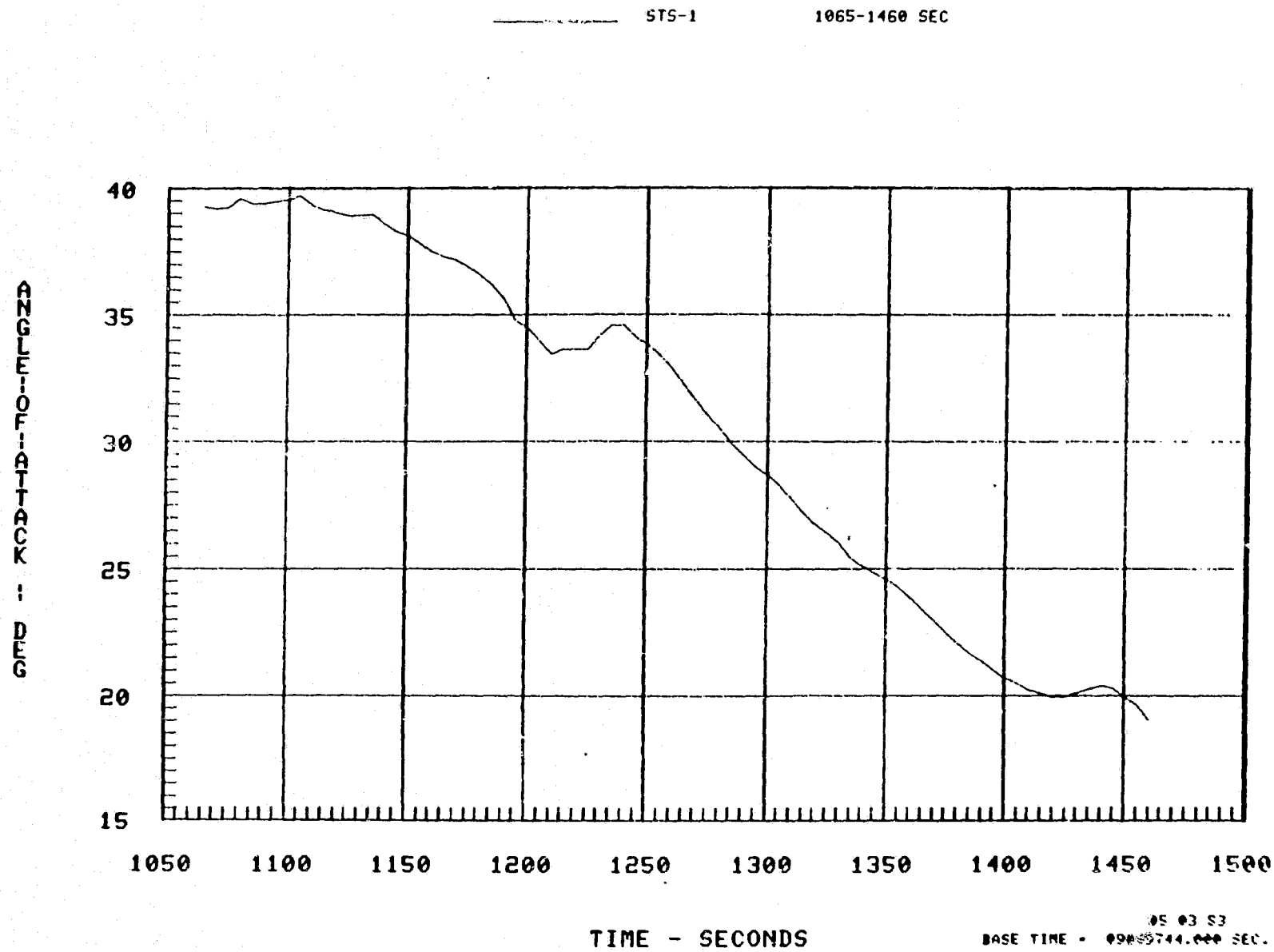
Table III - Continued

Measurement			STS-1	STS-2	STS-3	STS-4	STS-5
			STS - Flight				
V07T9707A - h/h_{ref}	vs	α	296	297	n/a	298	299
- h/h_{ref}	vs	M_∞	300	301	n/a	302	303
- h/h_{ref}	vs	Re_{NS}	304	305	n/a	306	307
- $\dot{q}_{conv}$	vs	t	308	309	n/a	310	311
- T_s	vs	t	312	313	n/a	314	315
V07T9708A - h/h_{ref}	vs	α	316	317	n/a	318	319
- h/h_{ref}	vs	M_∞	320	321	n/a	322	323
- h/h_{ref}	vs	Re_{NS}	324	325	n/a	326	327
- $\dot{q}_{conv}$	vs	t	328	329	n/a	330	331
- T_s	vs	t	332	333	n/a	334	335
V07T9710A - h/h_{ref}	vs	α	336	337	338	339	340
- h/h_{ref}	vs	M_∞	341	342	343	344	345
- h/h_{ref}	vs	Re_{NS}	346	347	348	349	350
- $\dot{q}_{conv}$	vs	t	351	352	353	354	355
- T_s	vs	t	356	357	358	359	360
V07T9711A - h/h_{ref}	vs	α	361	362	363	364	365
- h/h_{ref}	vs	M_∞	366	367	368	369	370
- h/h_{ref}	vs	Re_{NS}	371	372	373	374	375
- $\dot{q}_{conv}$	vs	t	376	377	378	379	380
- T_s	vs	t	381	382	383	384	385
V07T9713A - h/h_{ref}	vs	α	386	387	388	389	390
- h/h_{ref}	vs	M_∞	391	392	393	394	395
- h/h_{ref}	vs	Re_{NS}	396	397	398	399	400
- $\dot{q}_{conv}$	vs	t	401	402	403	404	405
- T_s	vs	t	406	407	408	409	410
V07T9714A - h/h_{ref}	vs	α	411	412	413	414	415
- h/h_{ref}	vs	M_∞	416	417	418	419	420
- h/h_{ref}	vs	Re_{NS}	421	422	423	424	425
- $\dot{q}_{conv}$	vs	t	426	427	428	429	430
- T_s	vs	t	431	432	433	434	435

APPENDIX A

CORRELATION PARAMETERS

STS-1 (107 FT LENGTH WING) FLIGHT PARAMETER COMPARISON



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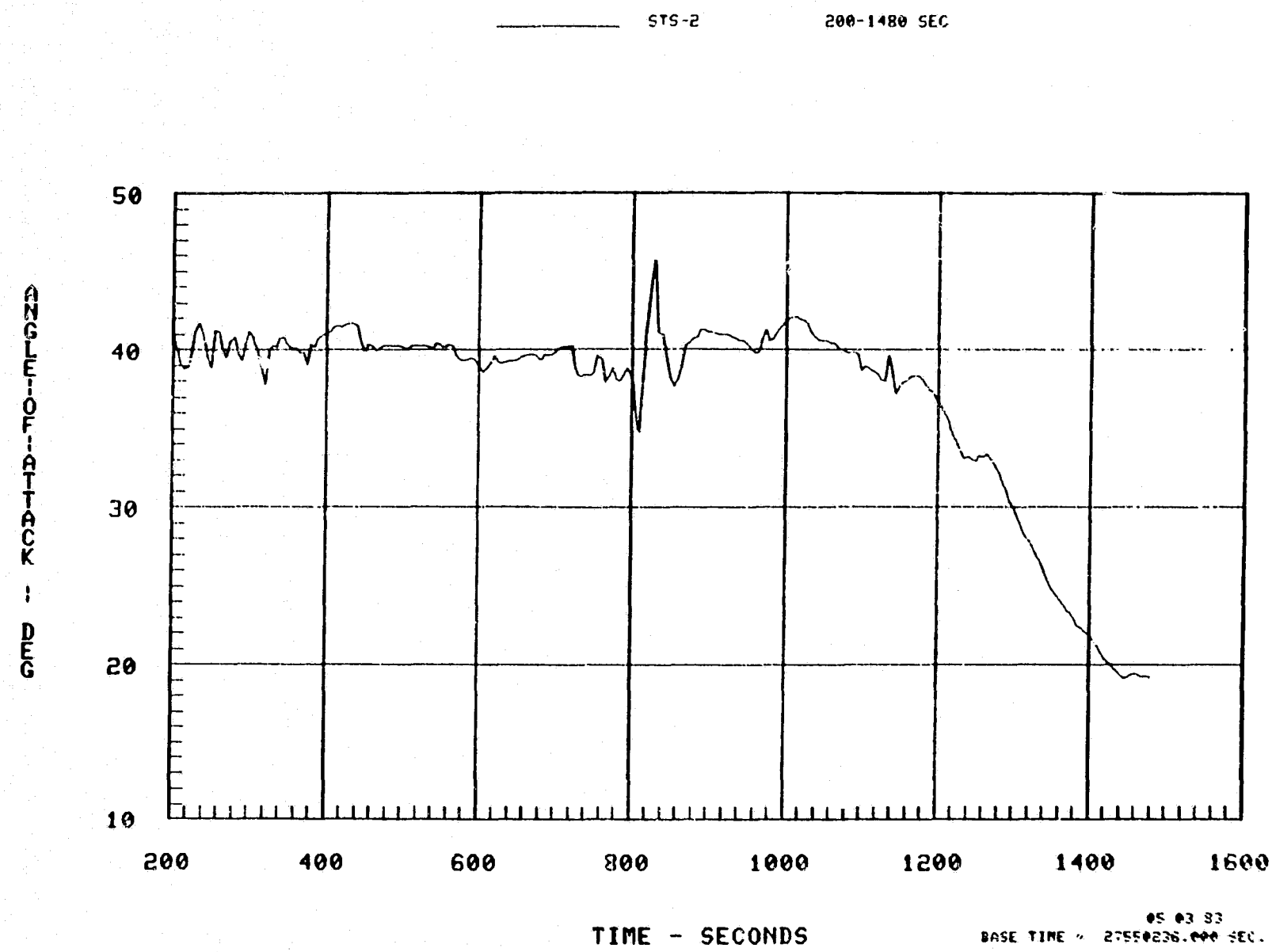

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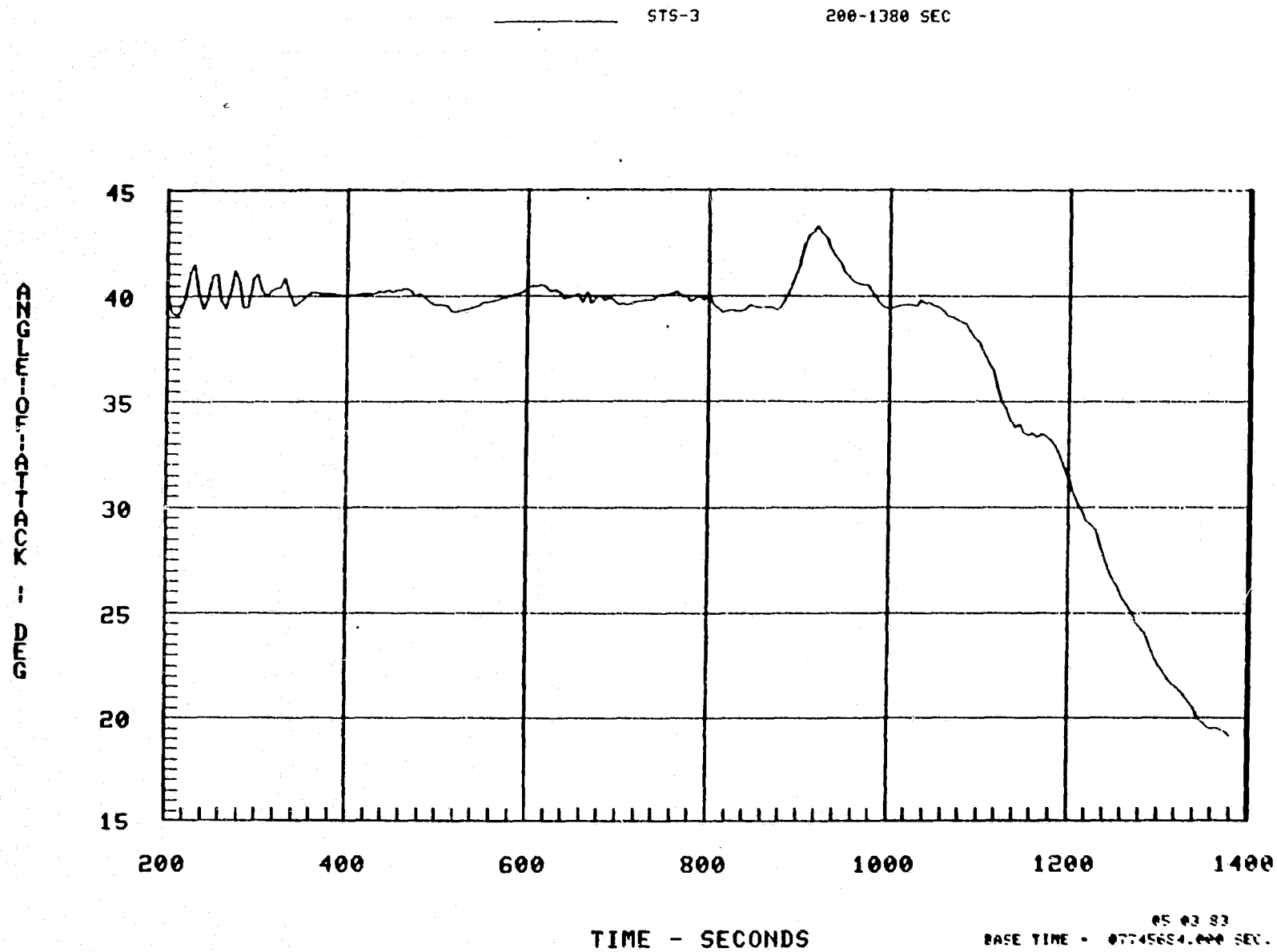
STS-3 (107 FT LENGTH WING) FLIGHT PARAMETER COMPARISON



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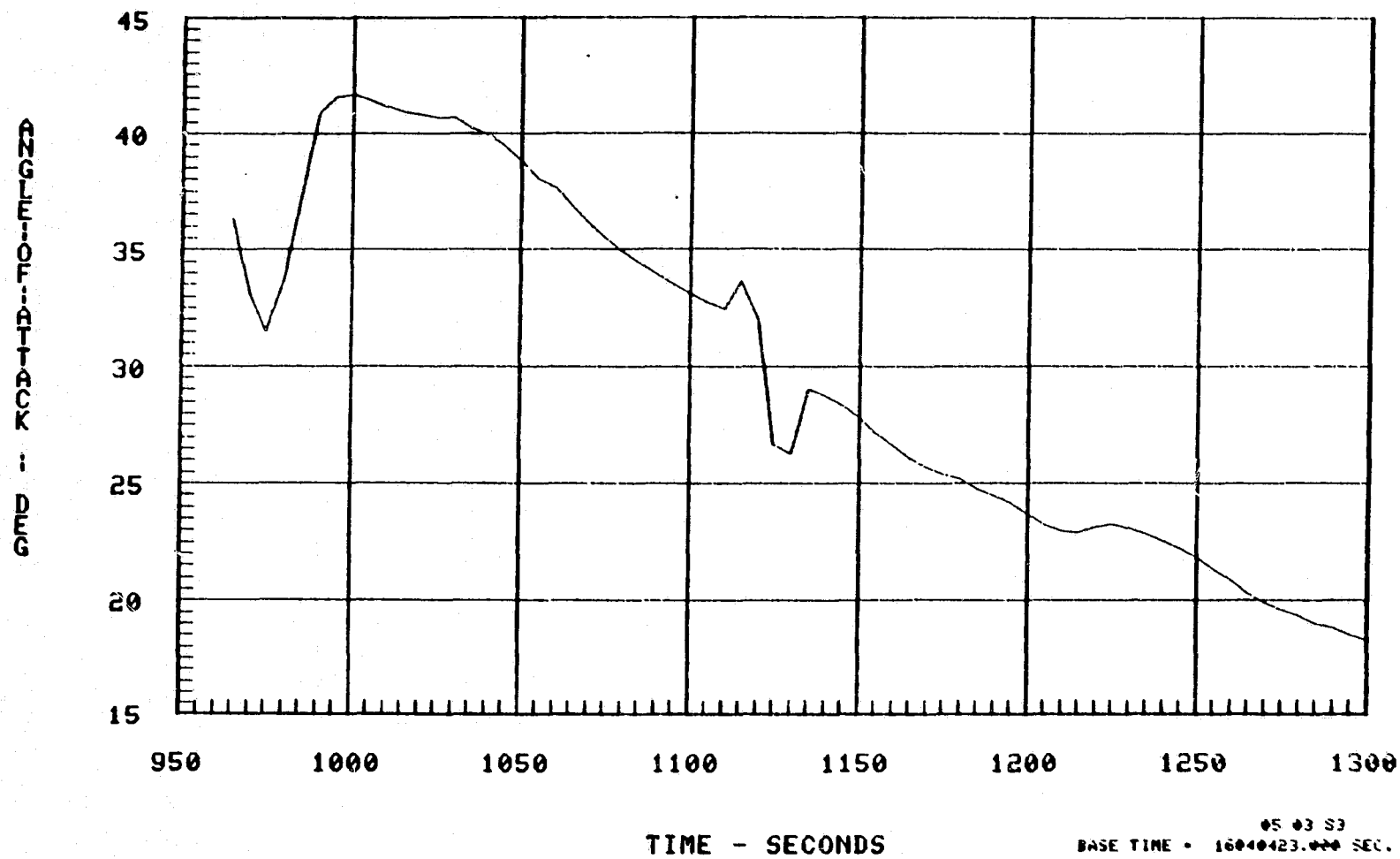

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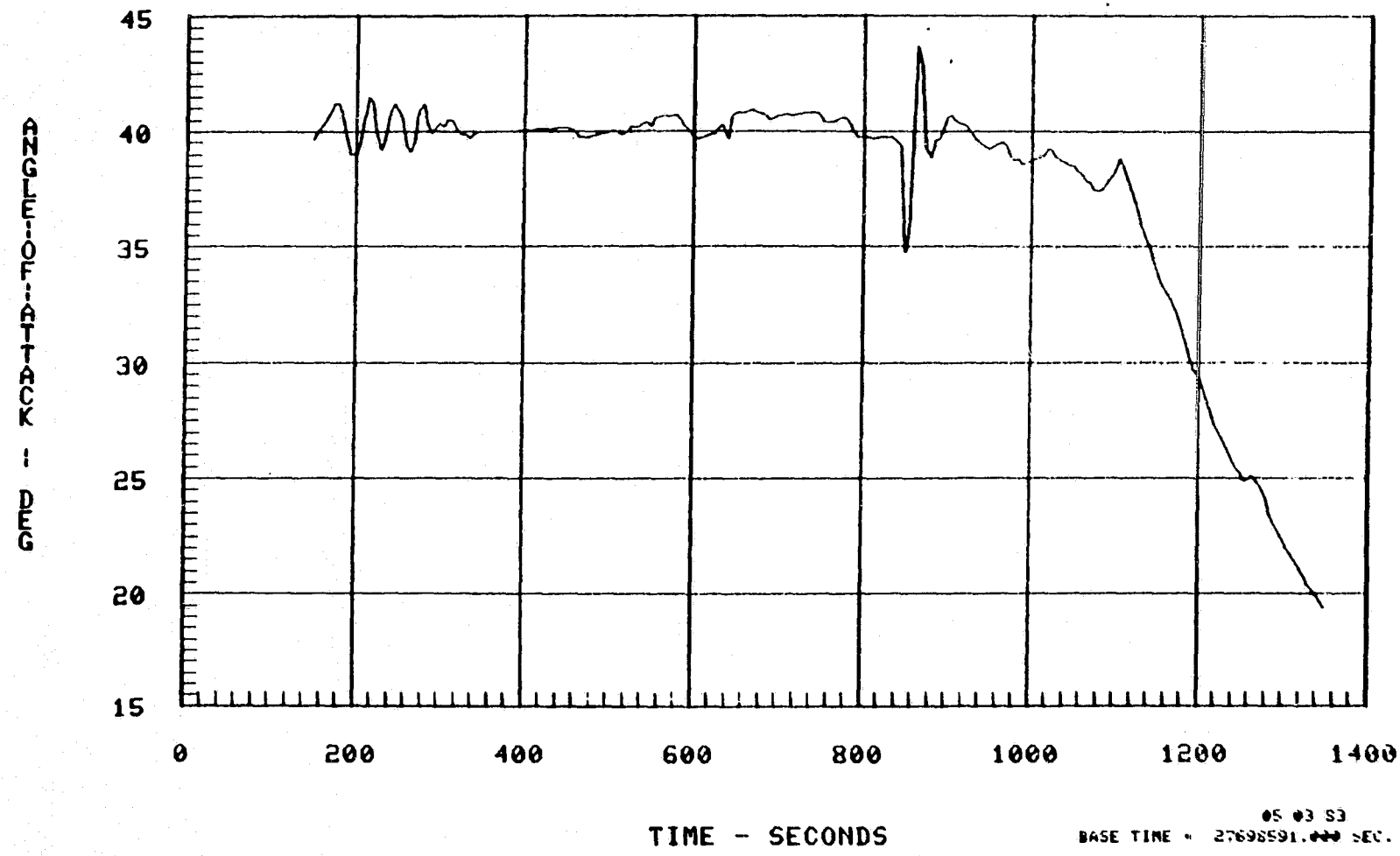

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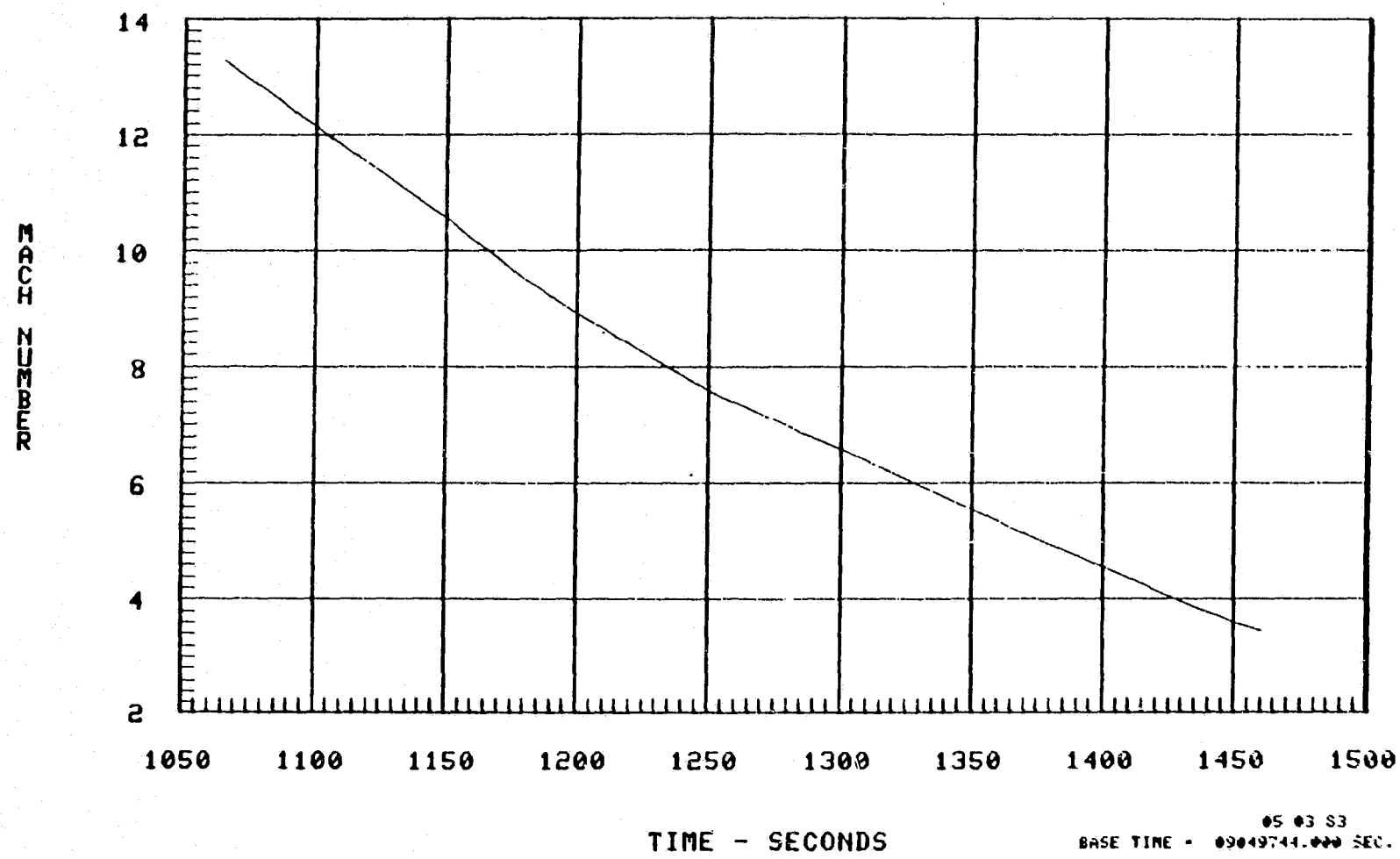

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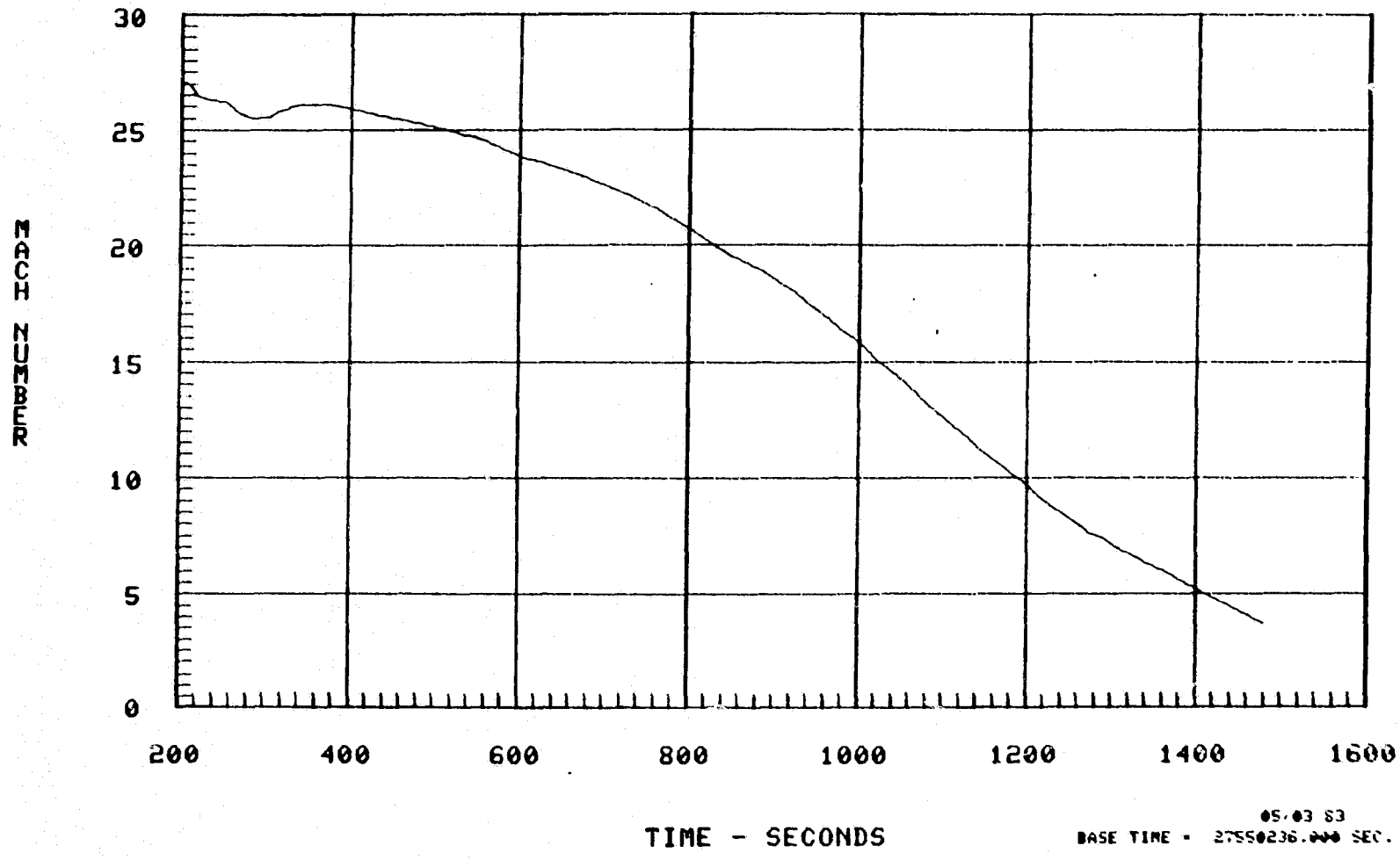

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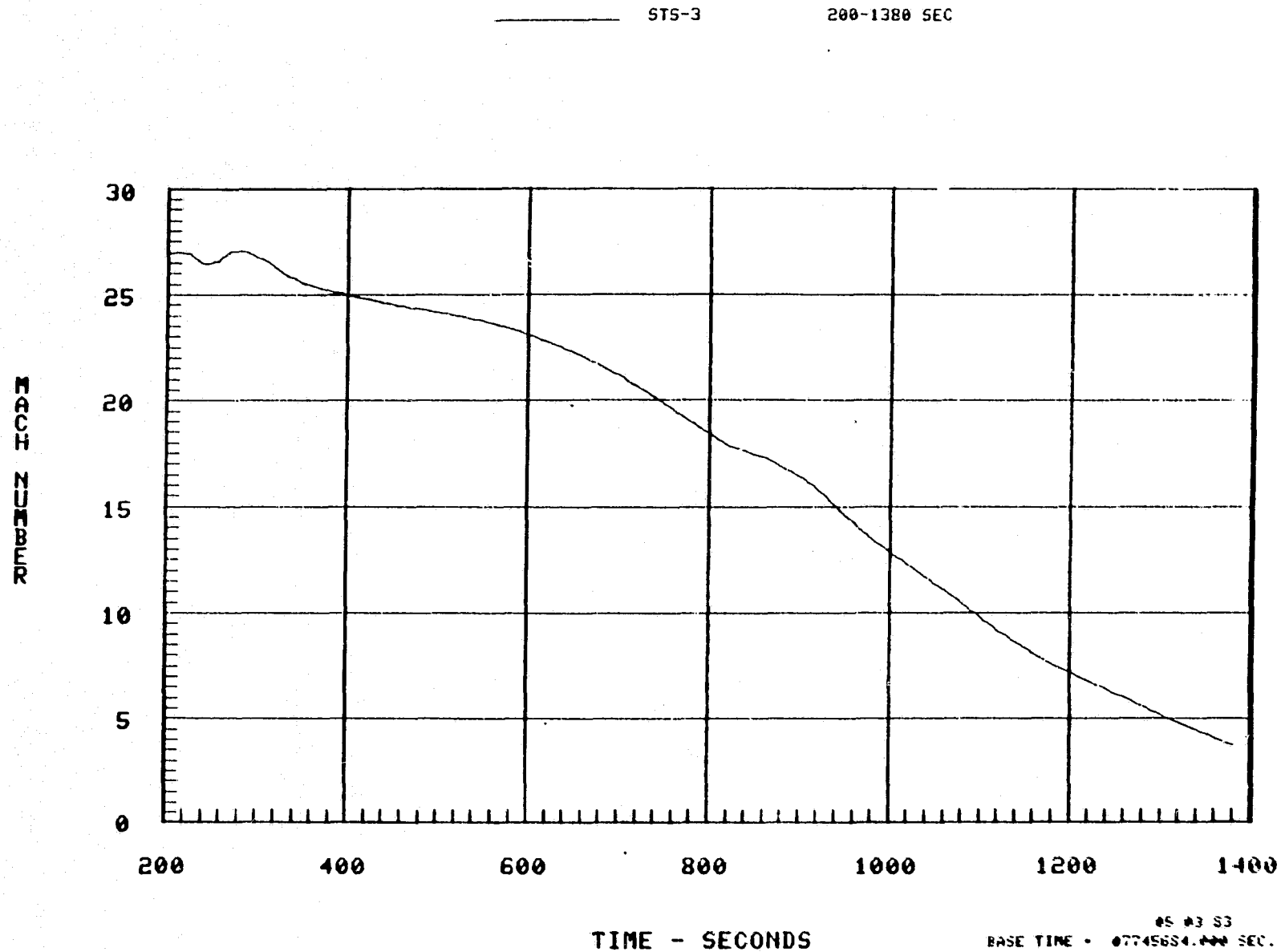

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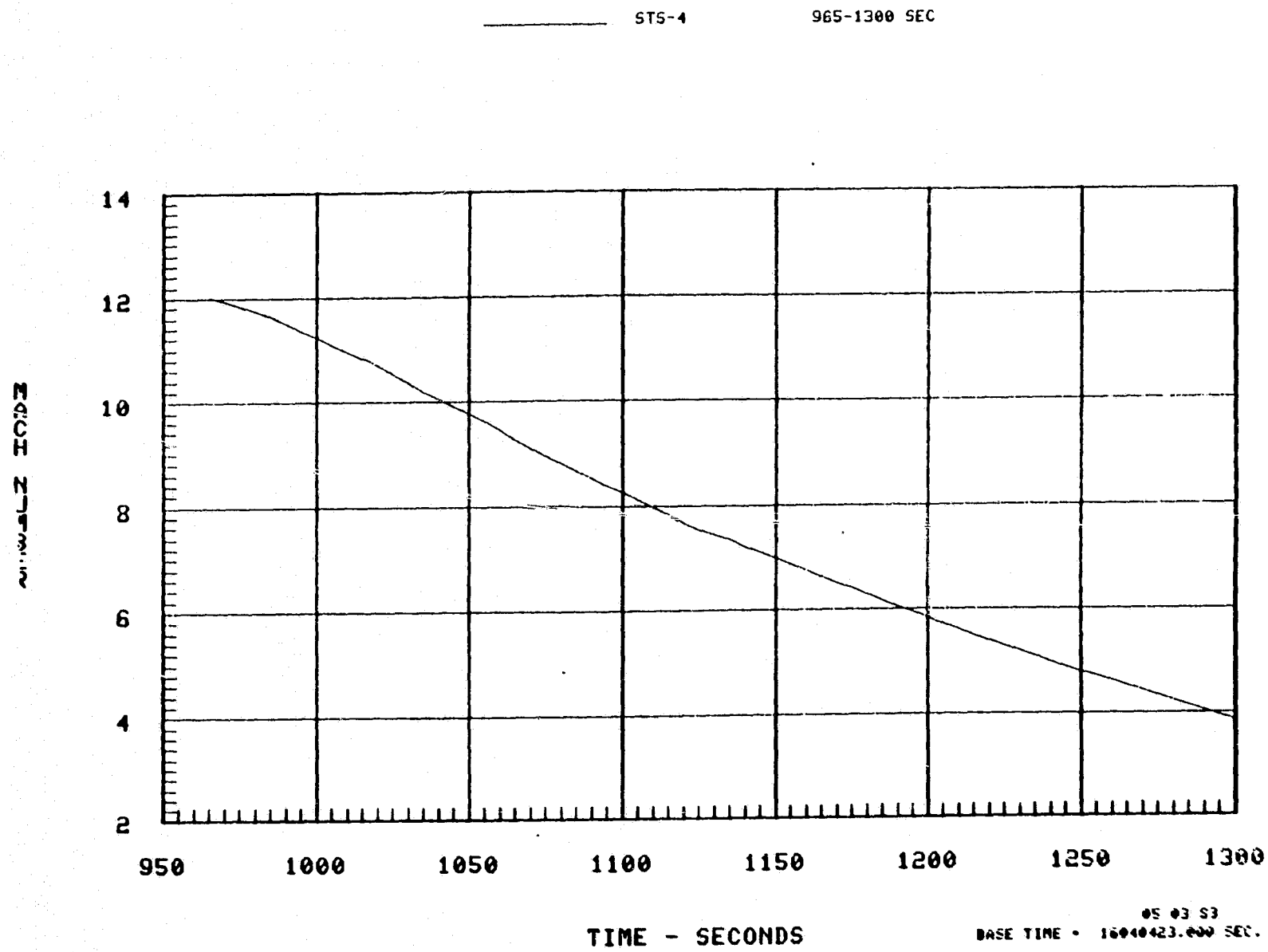

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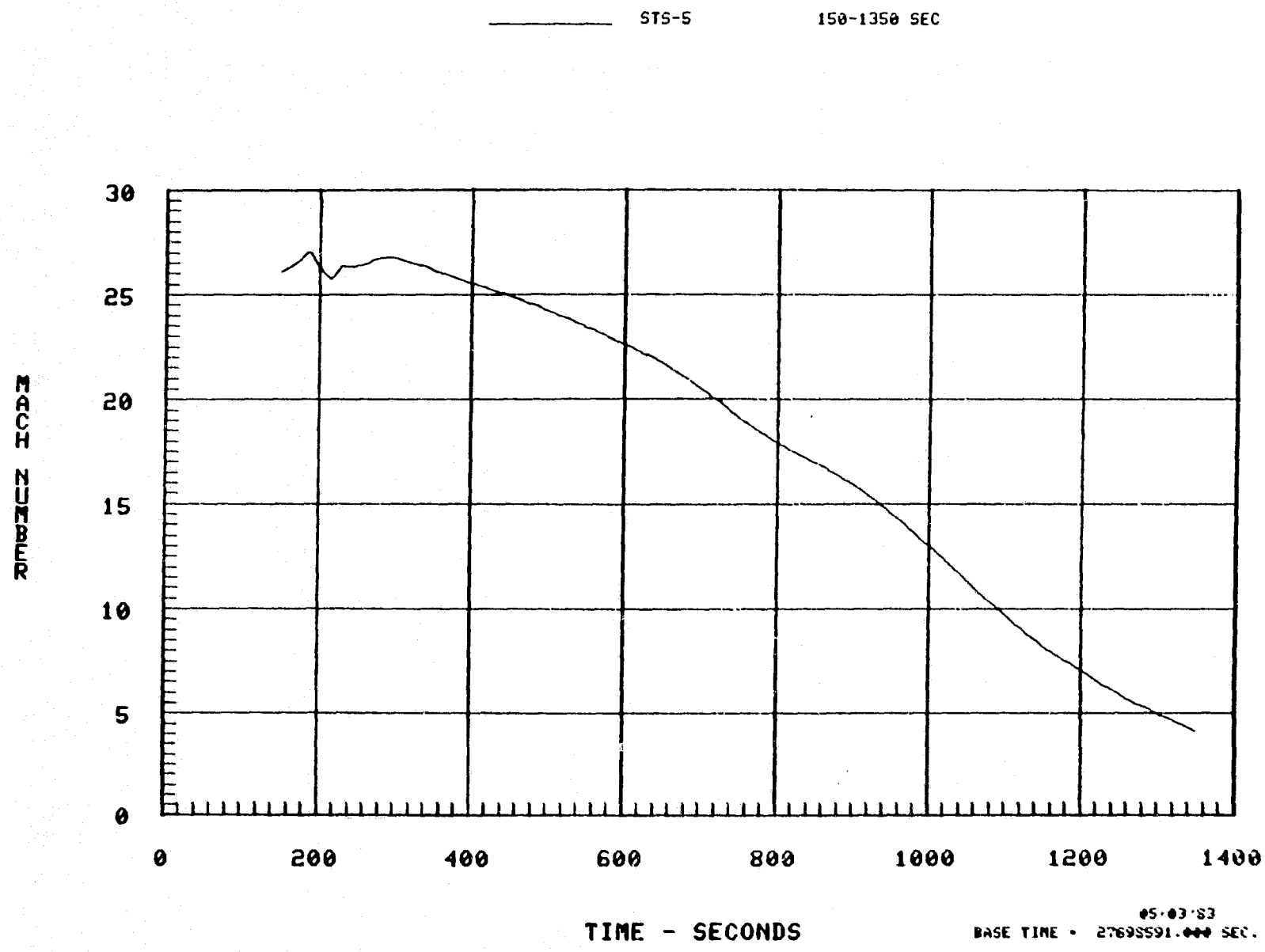

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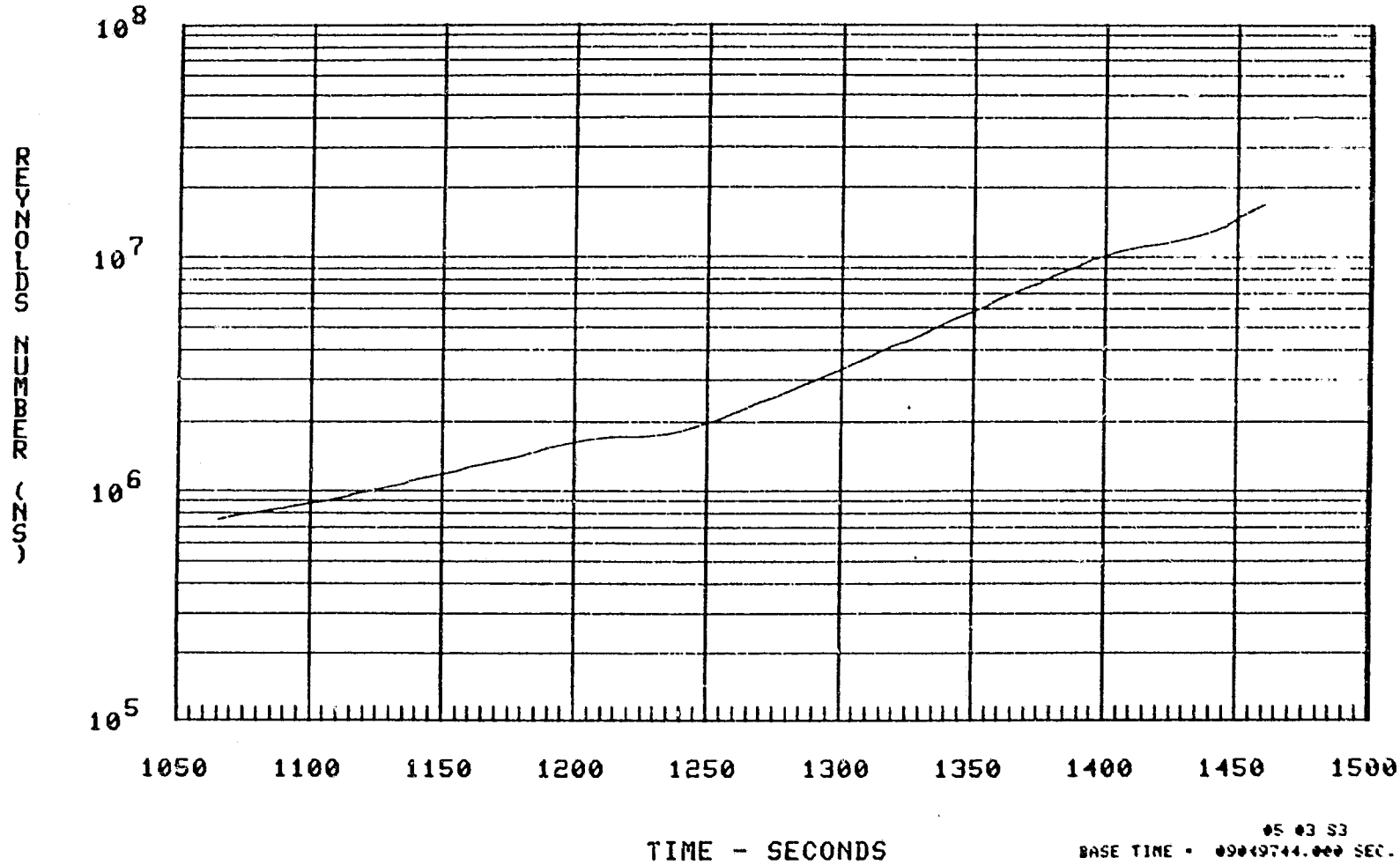

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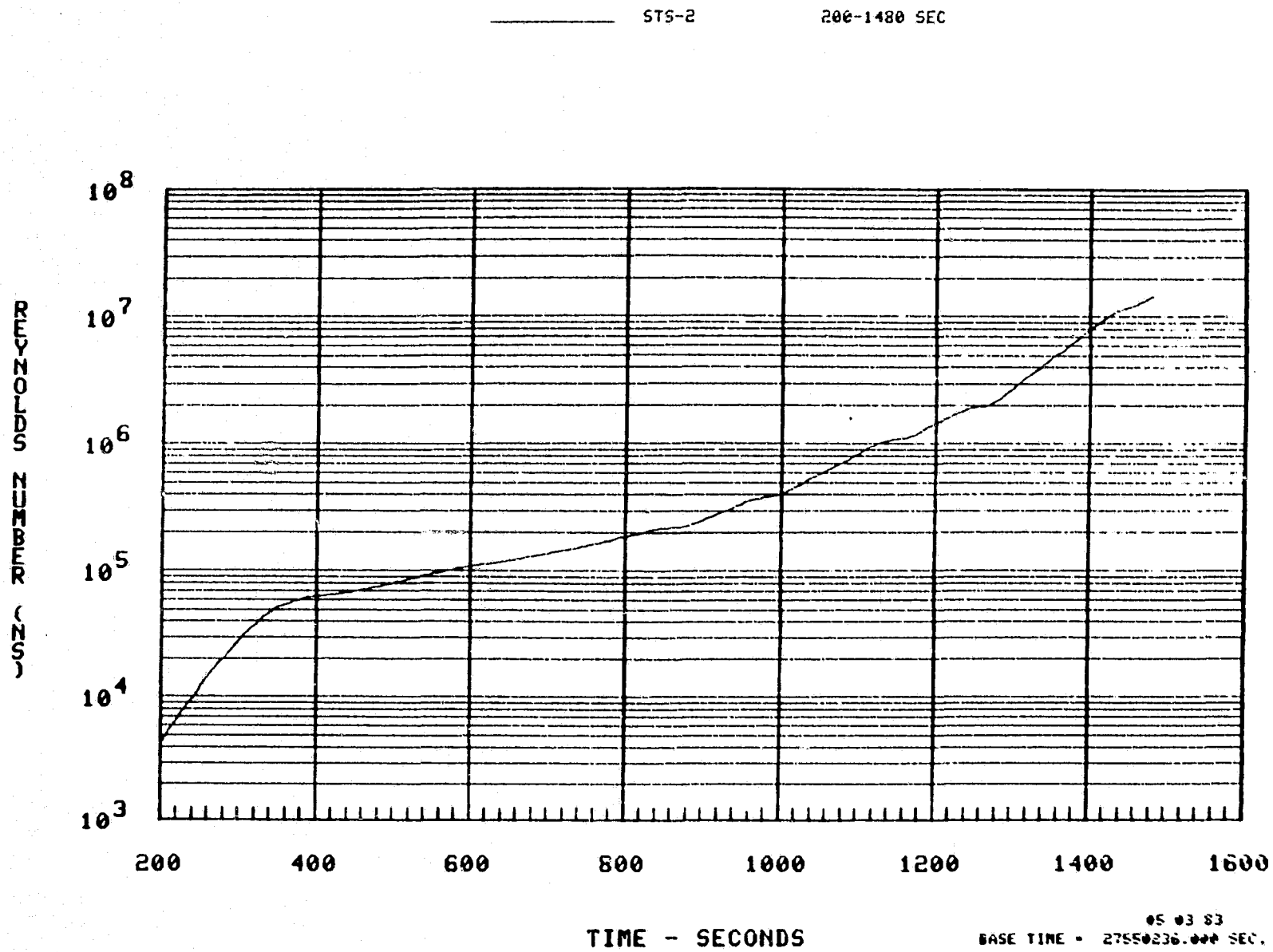

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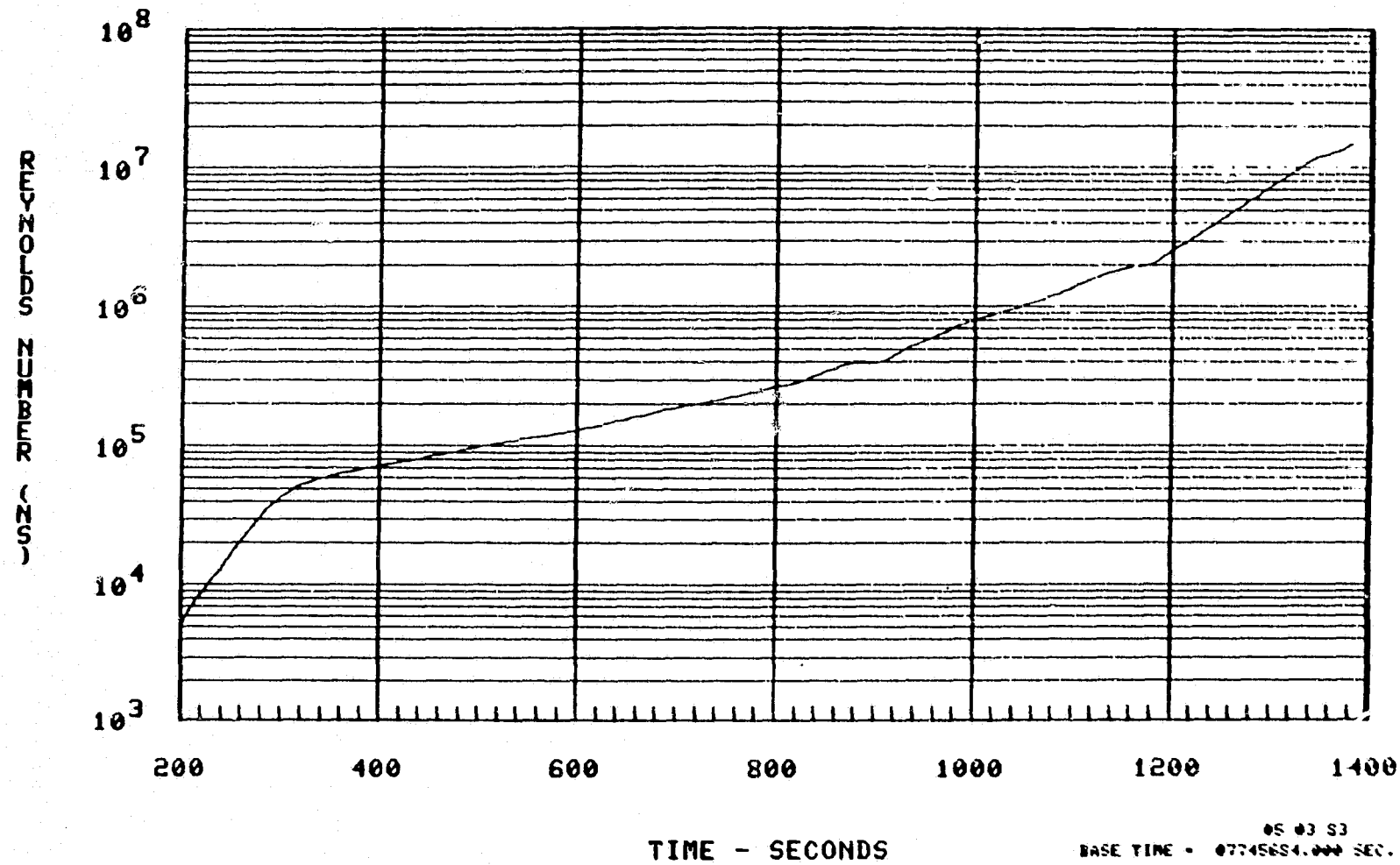
STS-3 (107 FT LENGTH WING) FLIGHT PARAMETER COMPARISON



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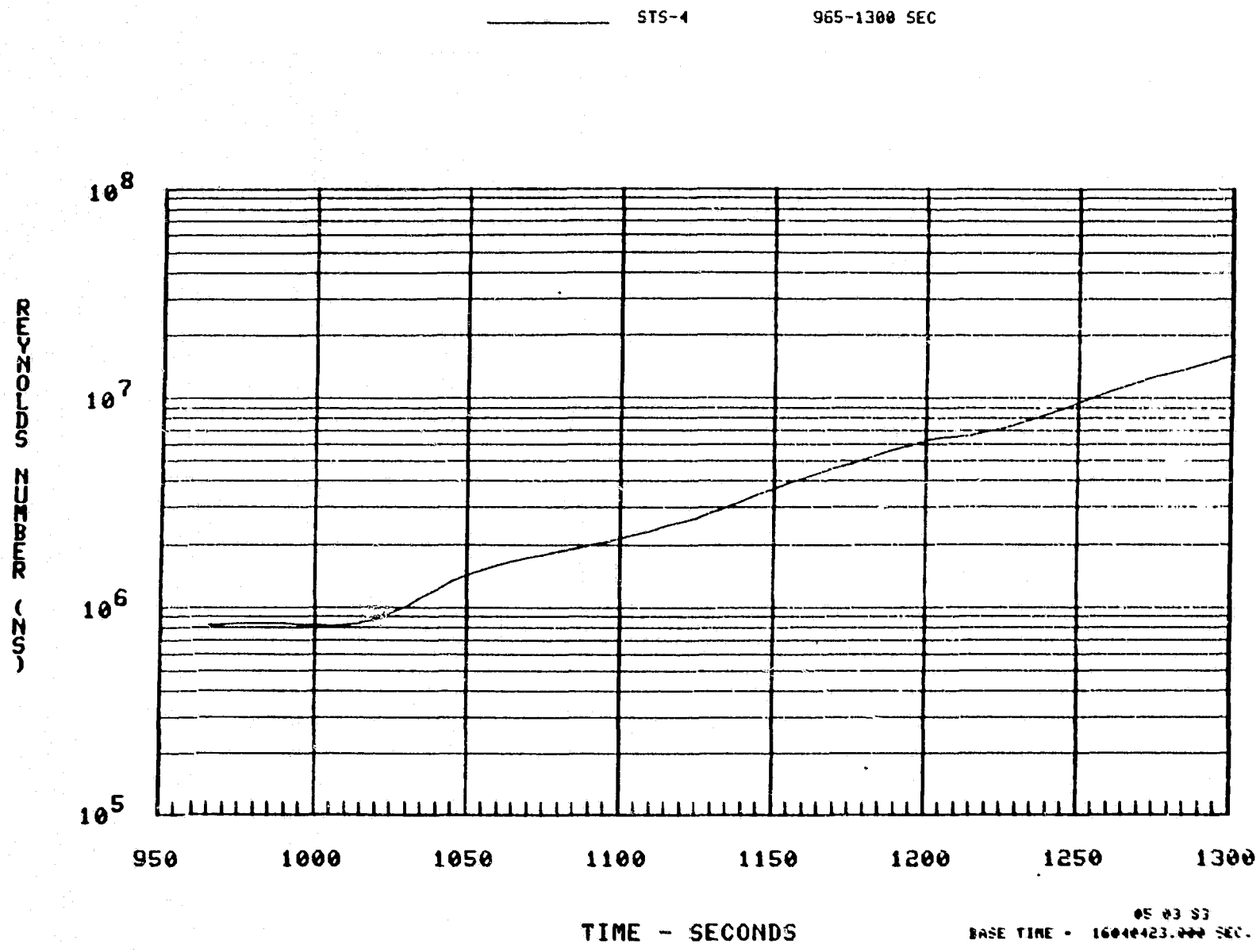

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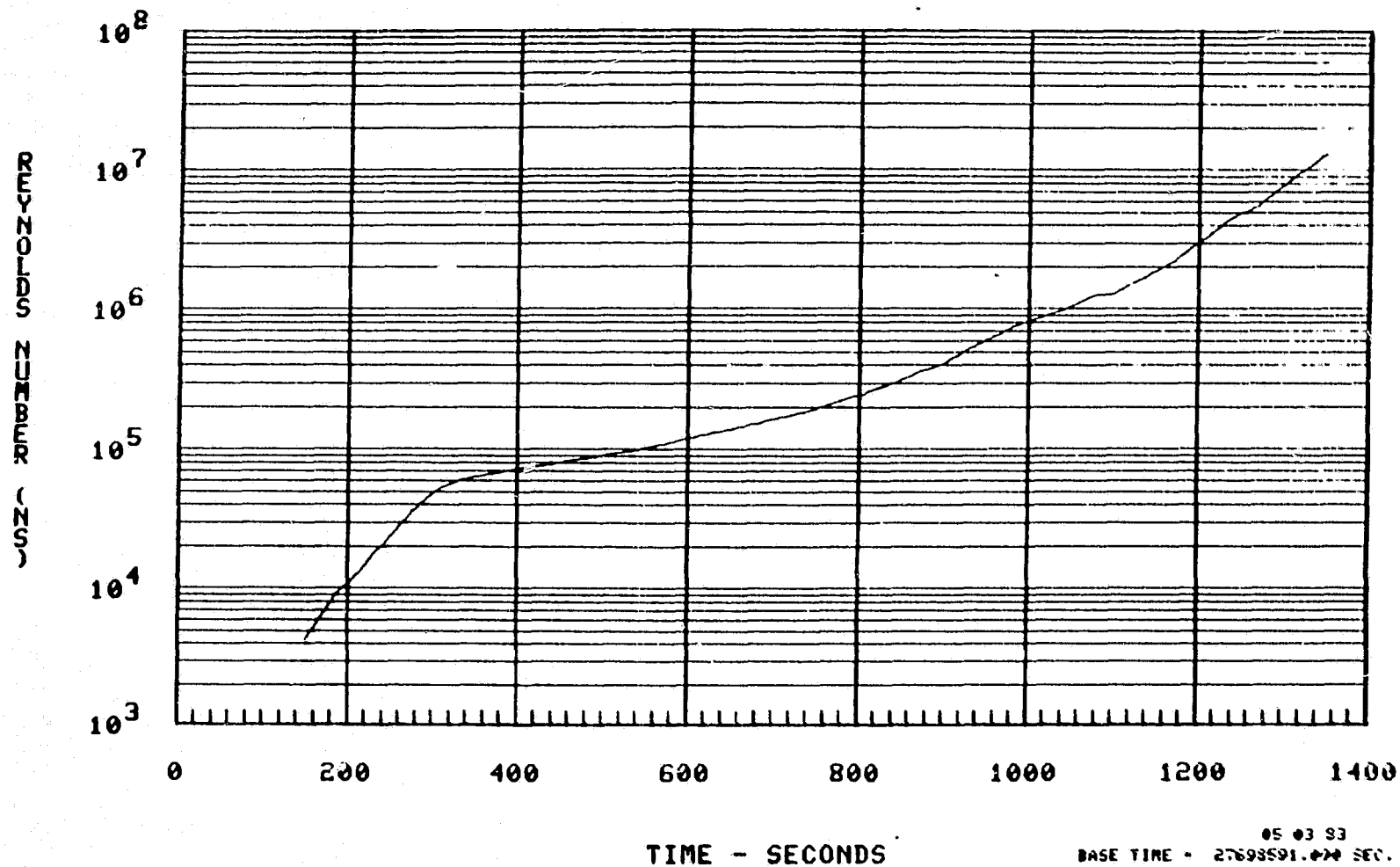
STS-5 (107 FT LENGTH WING) FLIGHT PARAMETER COMPARISON

STS-5 150-1350 SEC



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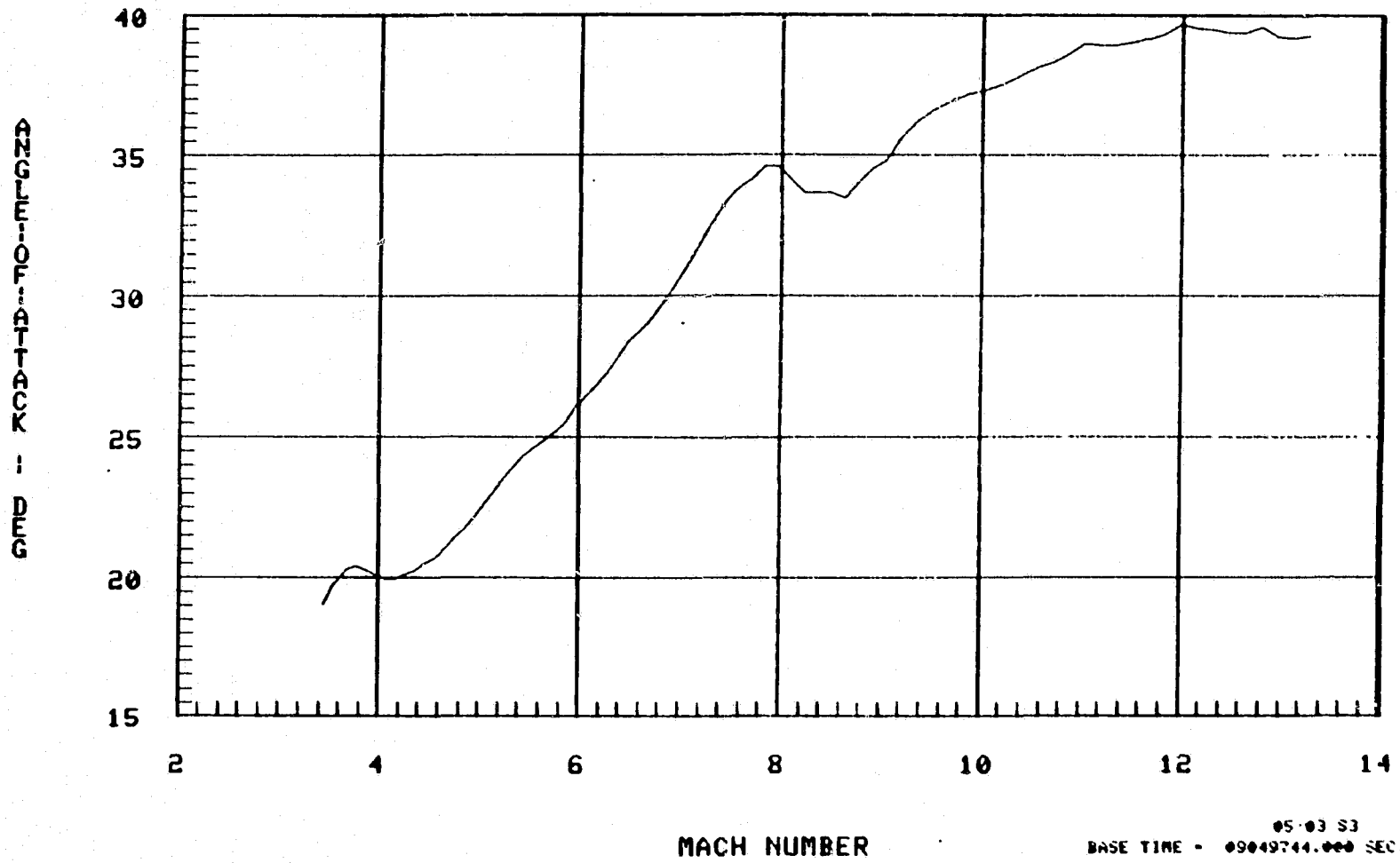

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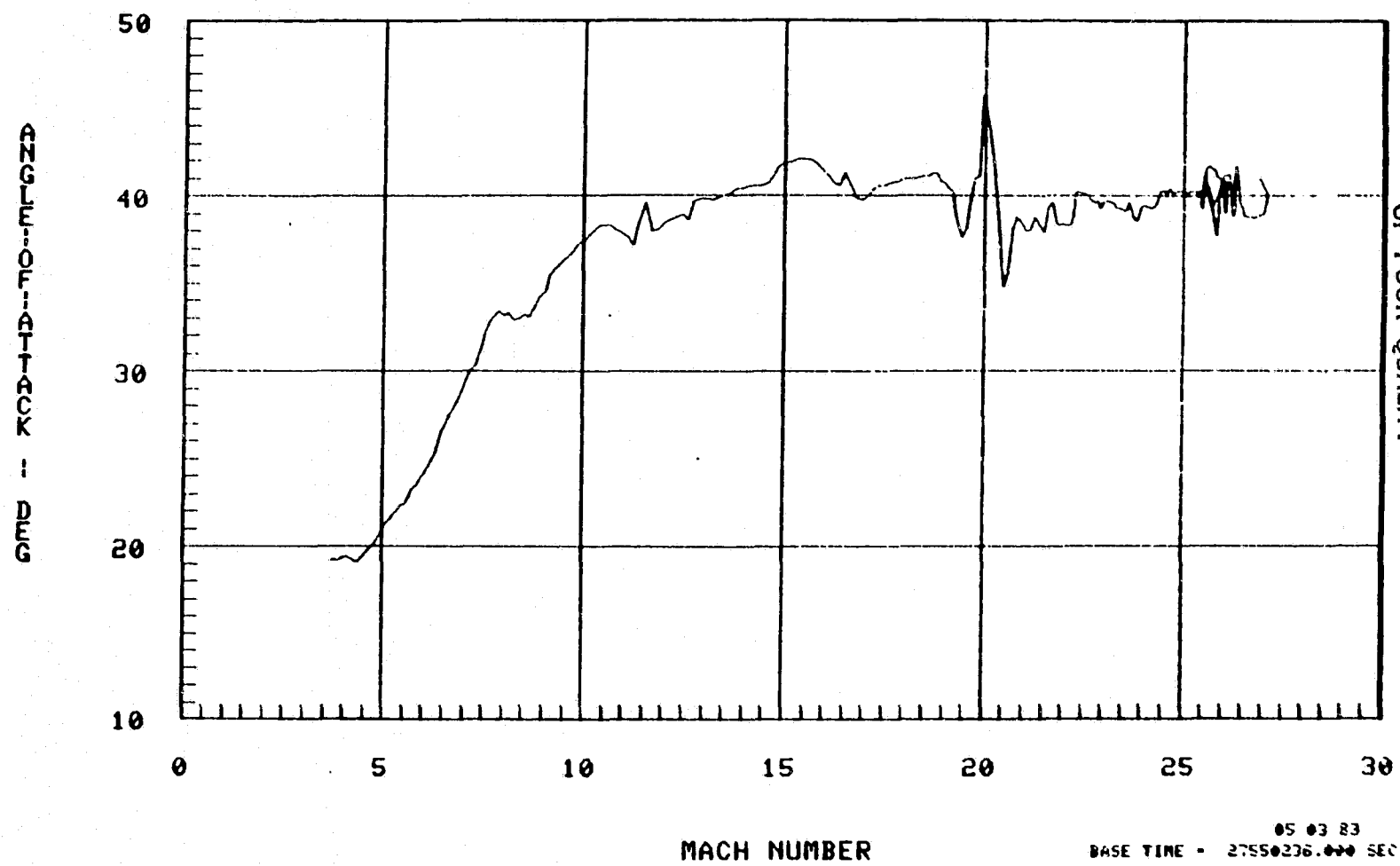
STS-2 (107 FT LENGTH WING) FLIGHT PARAMETER COMPARISON



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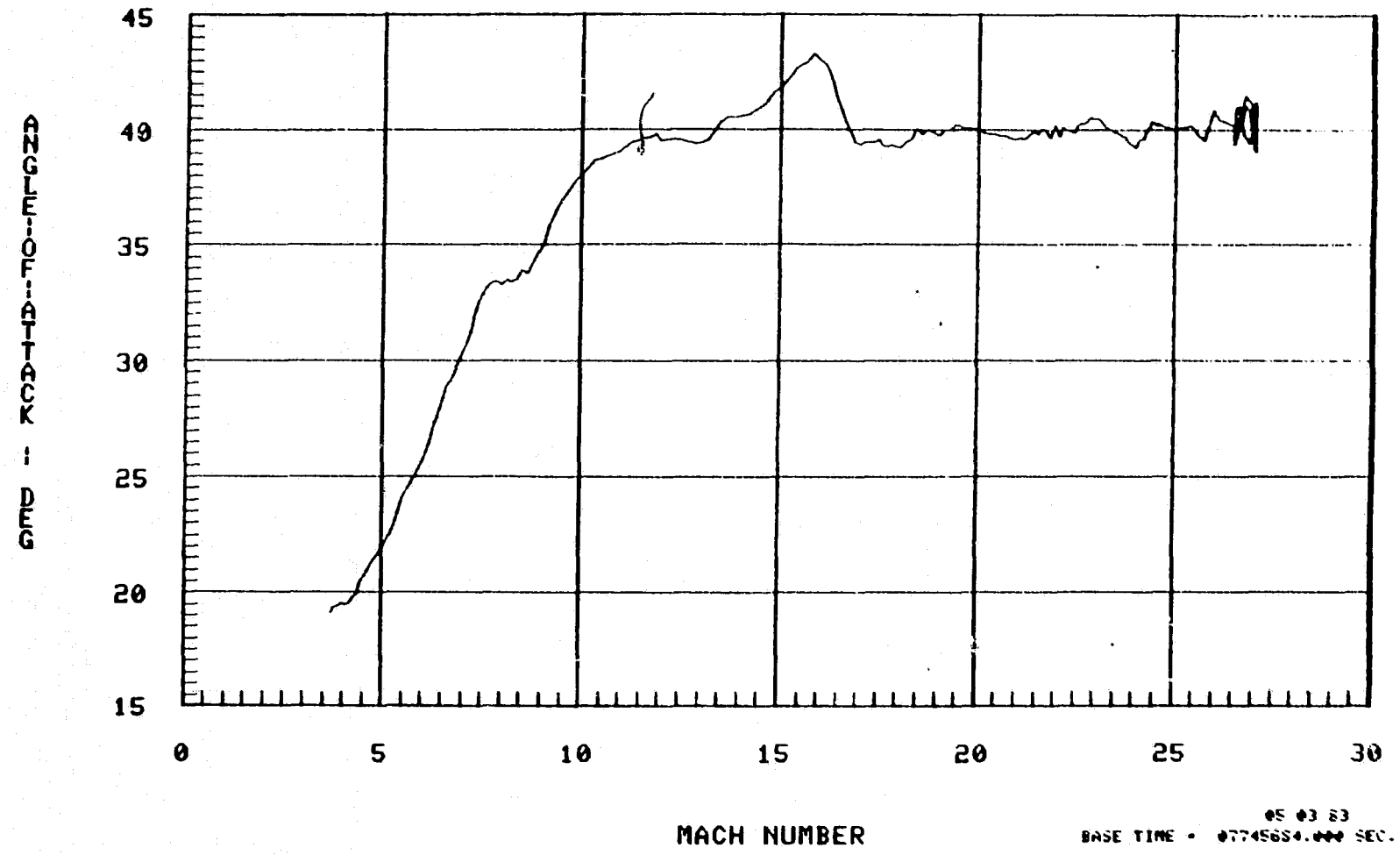

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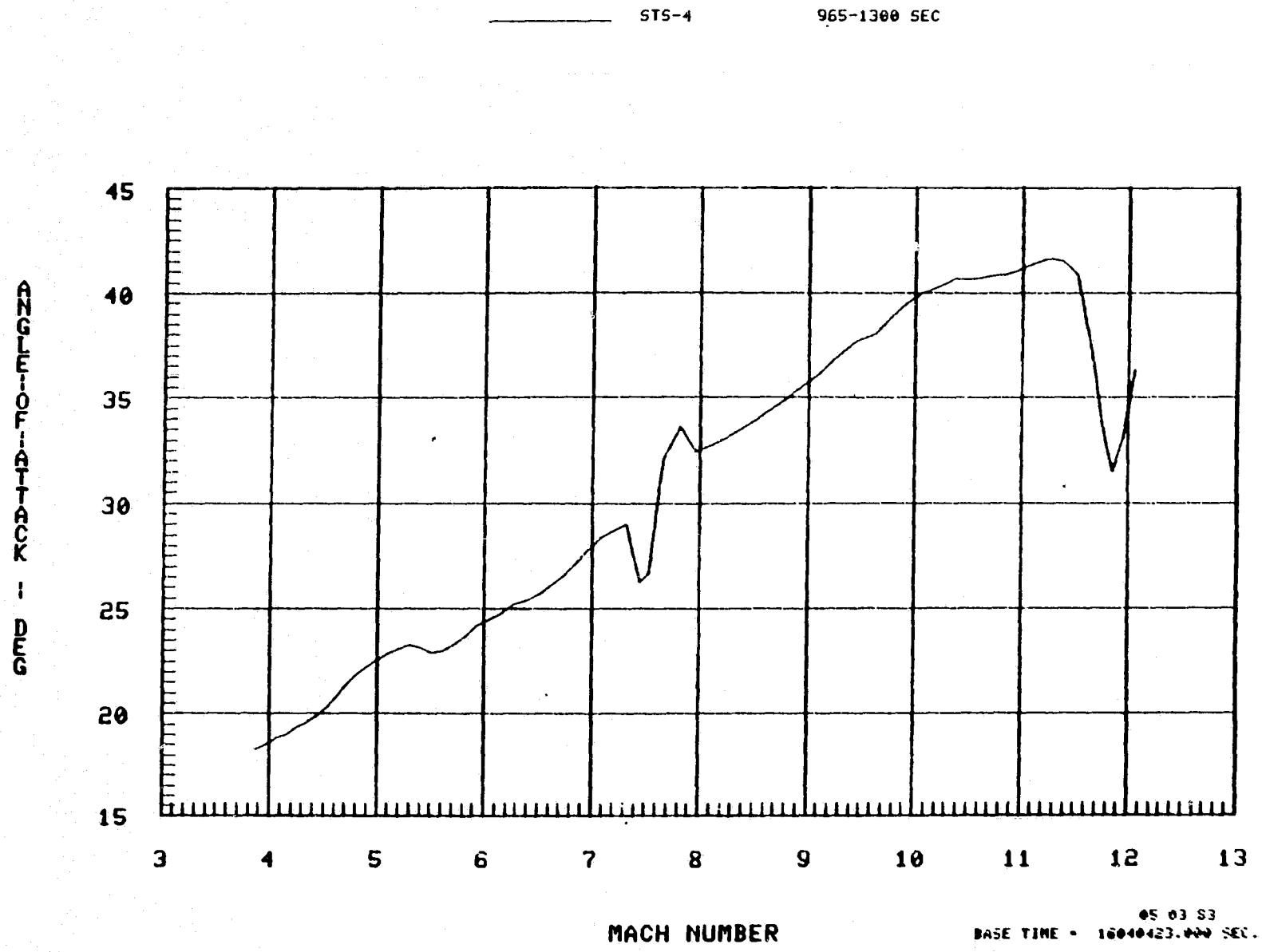

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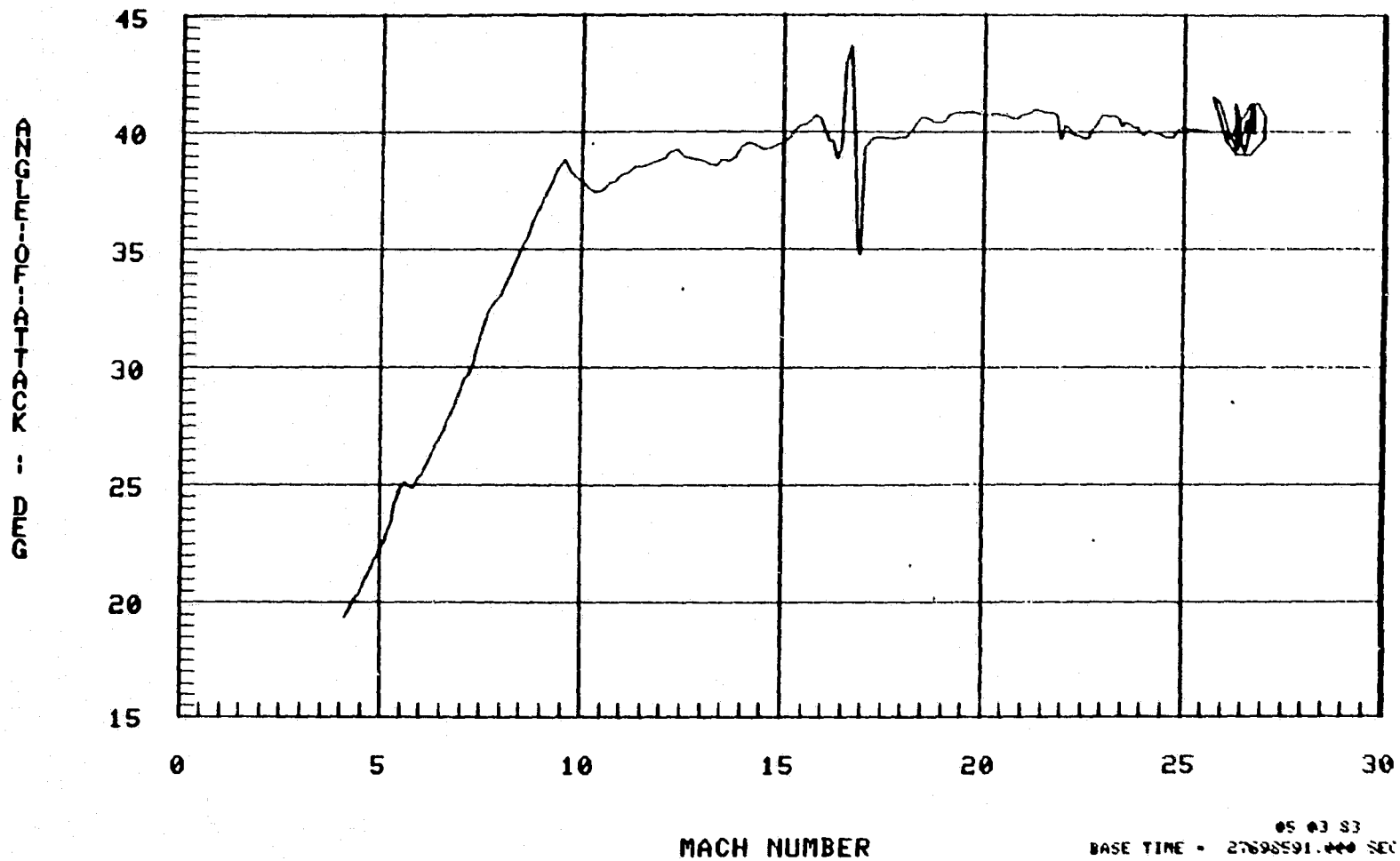

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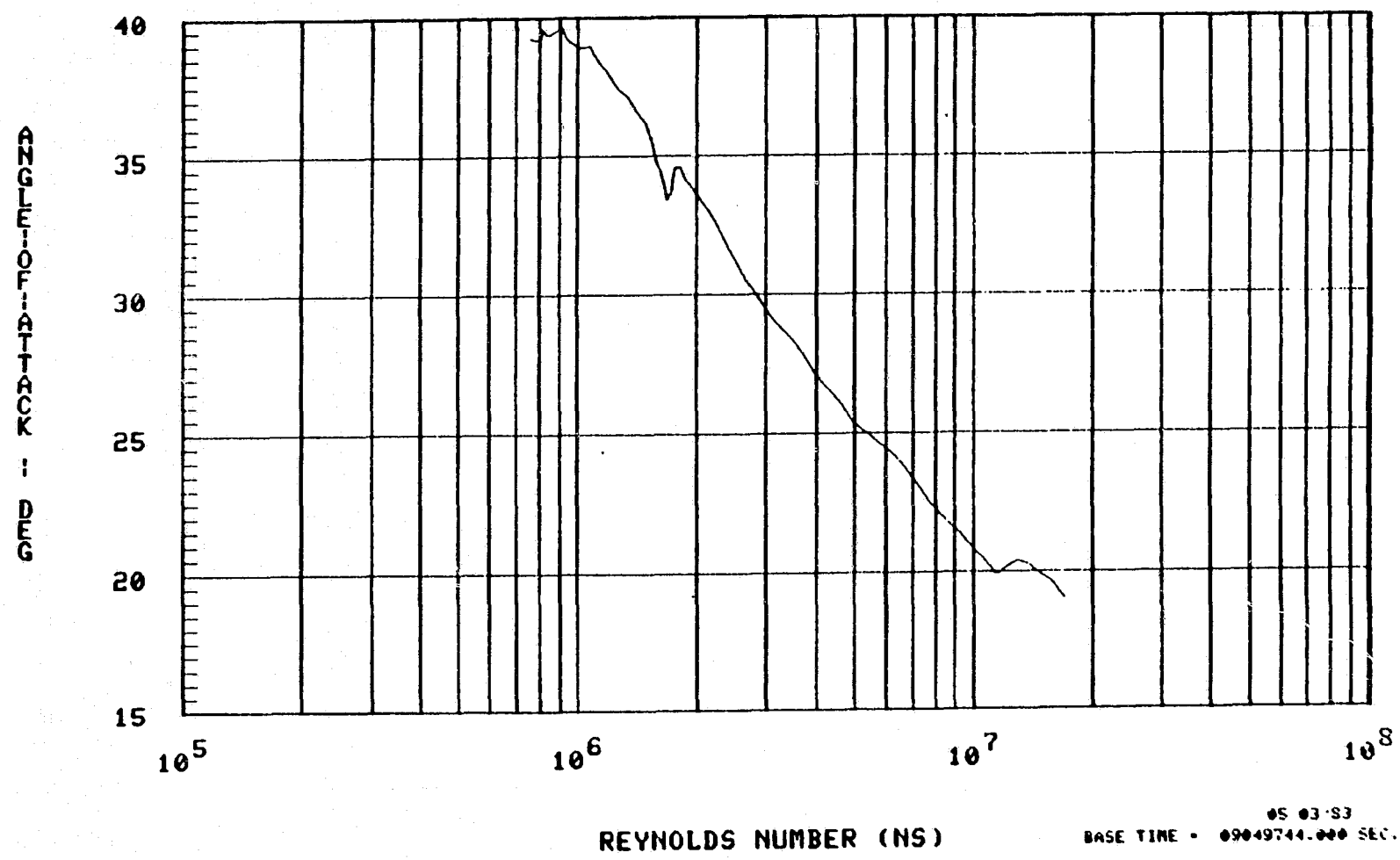

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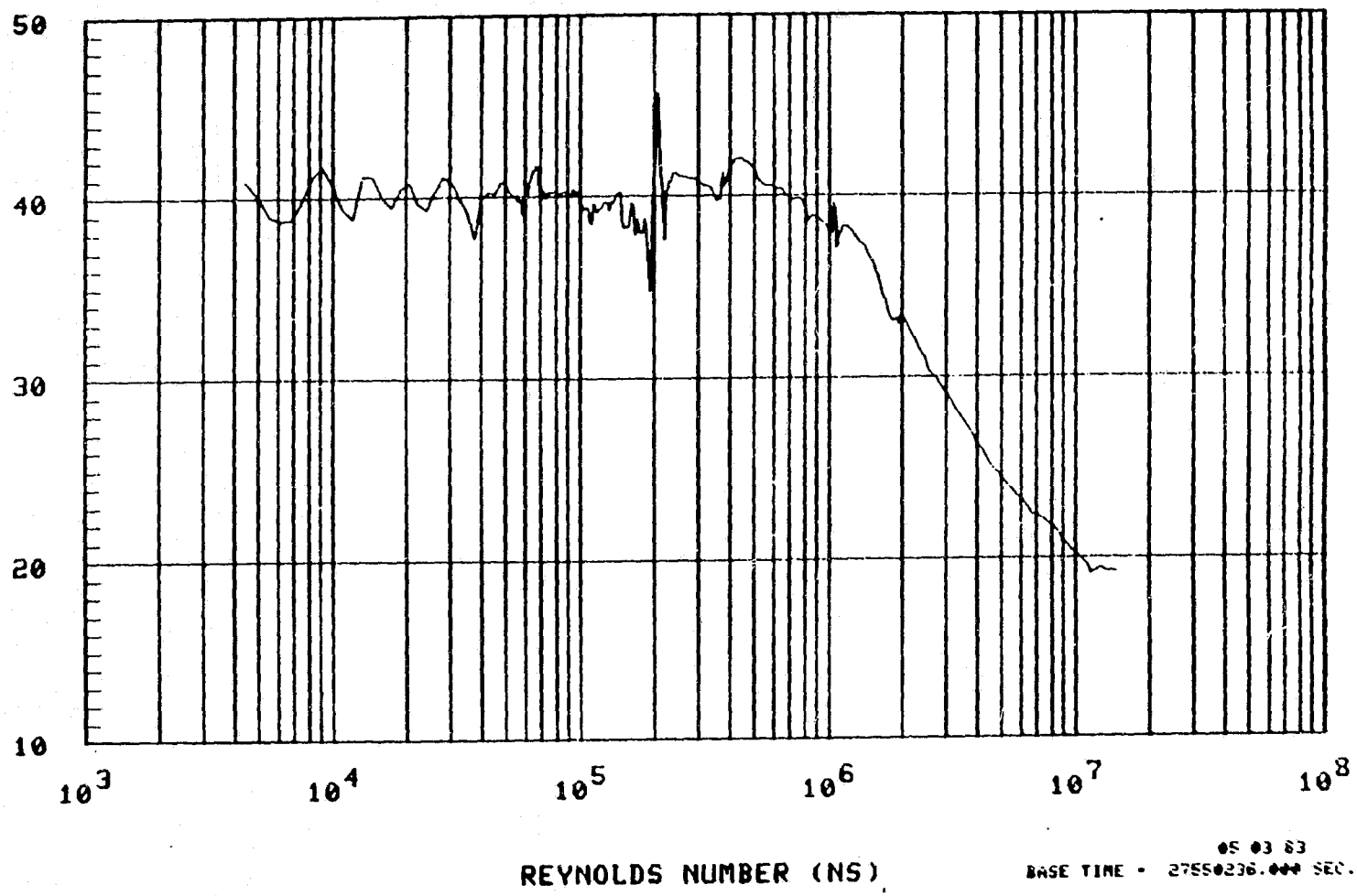

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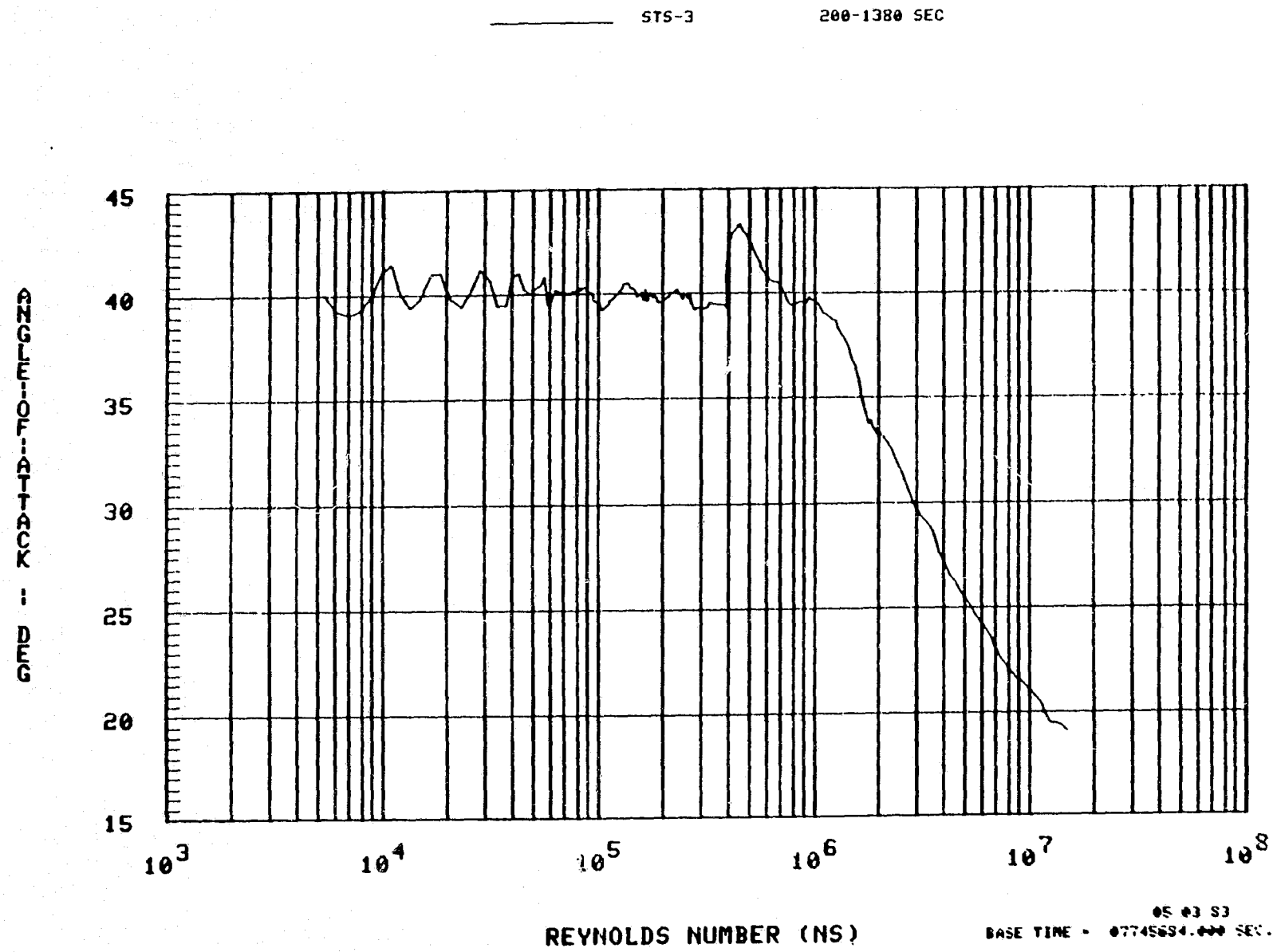

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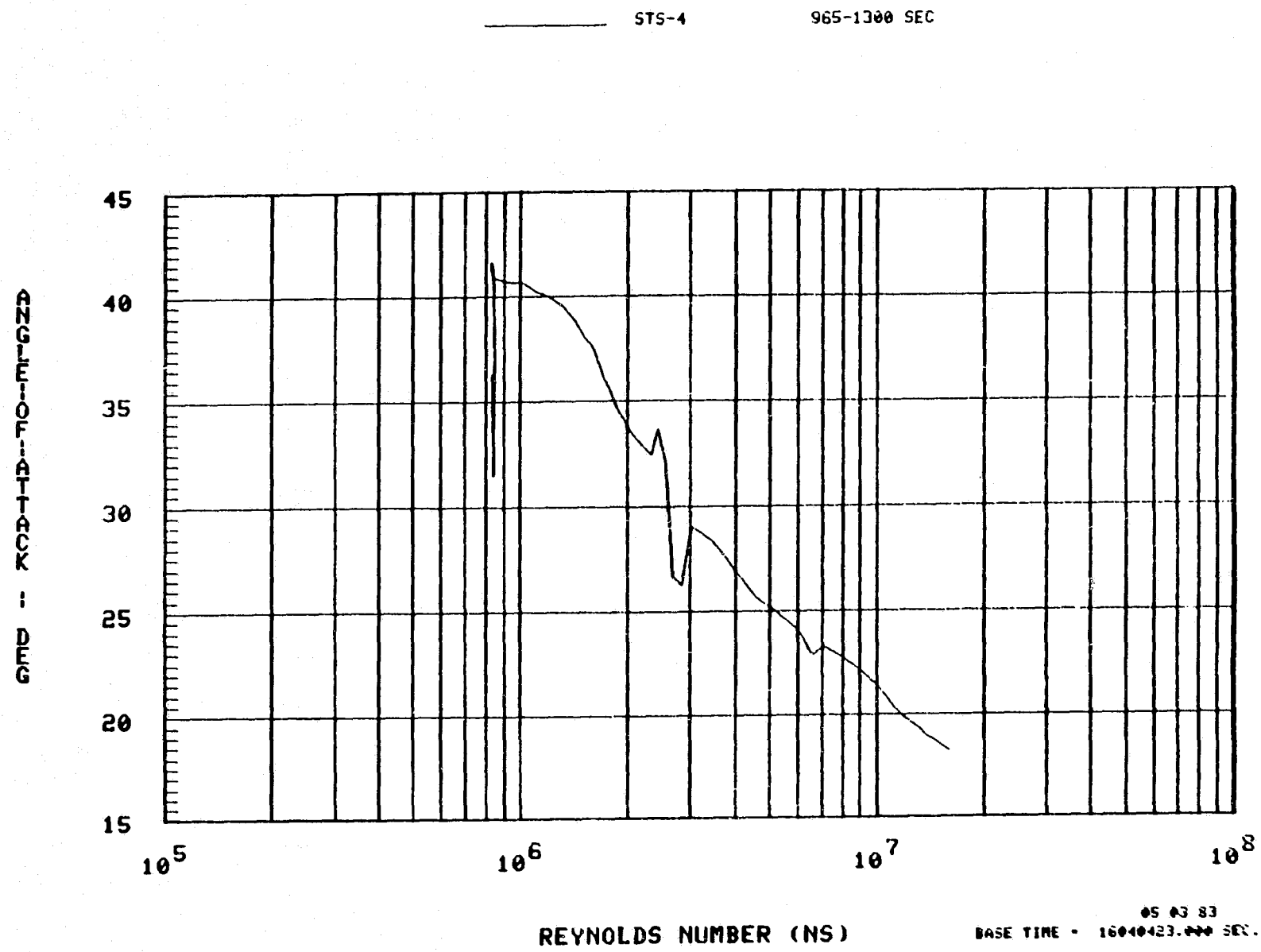

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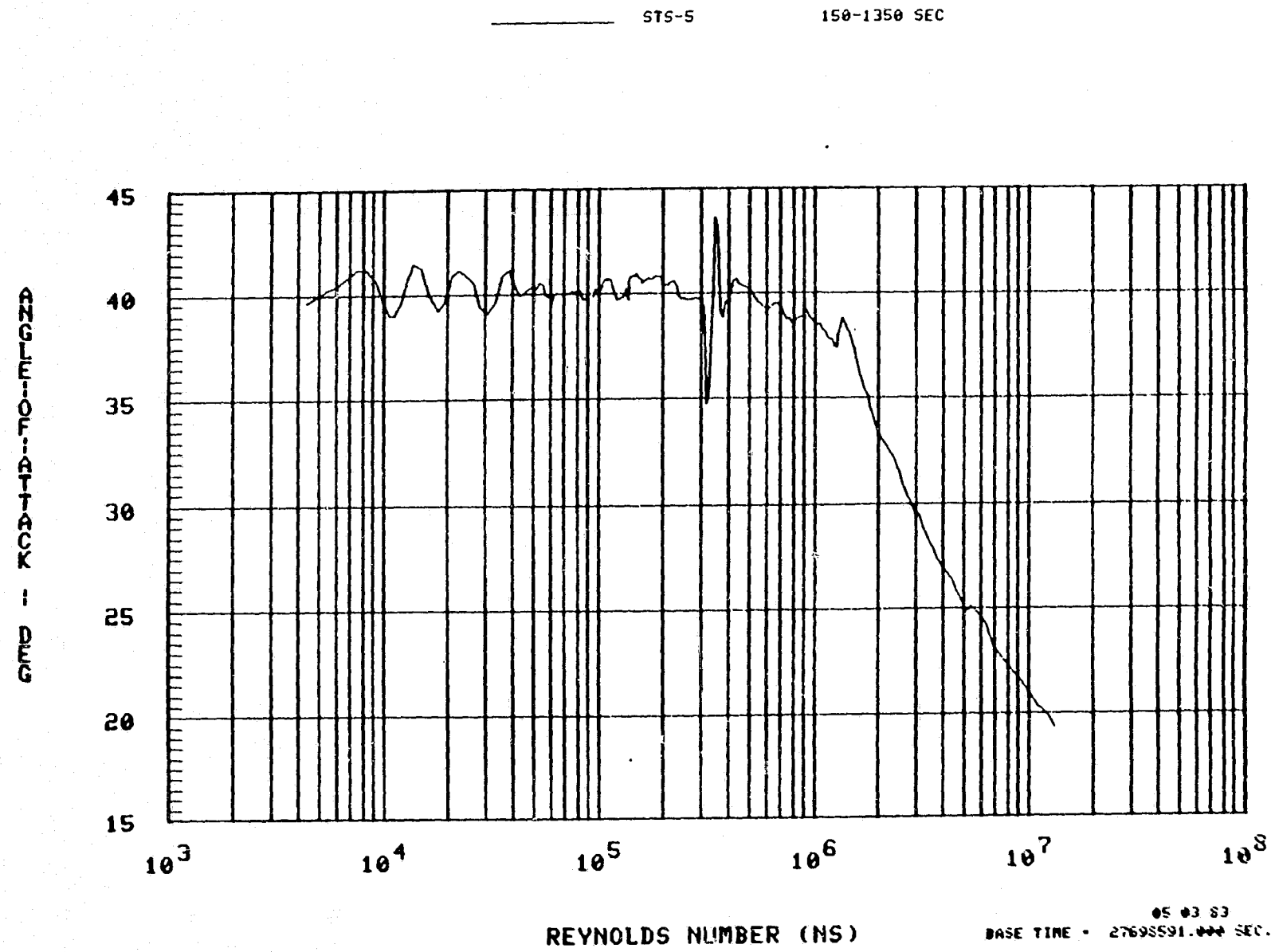

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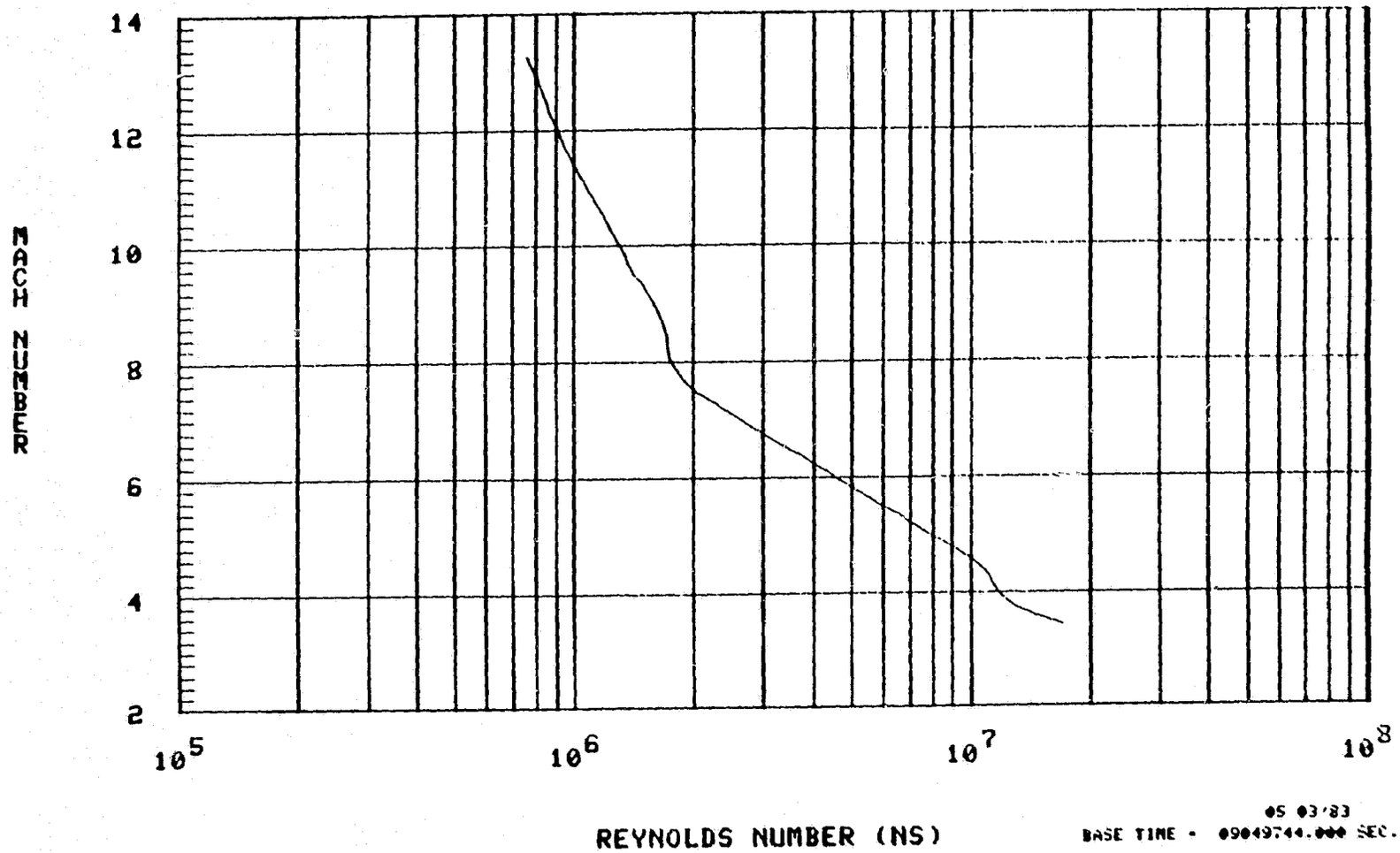

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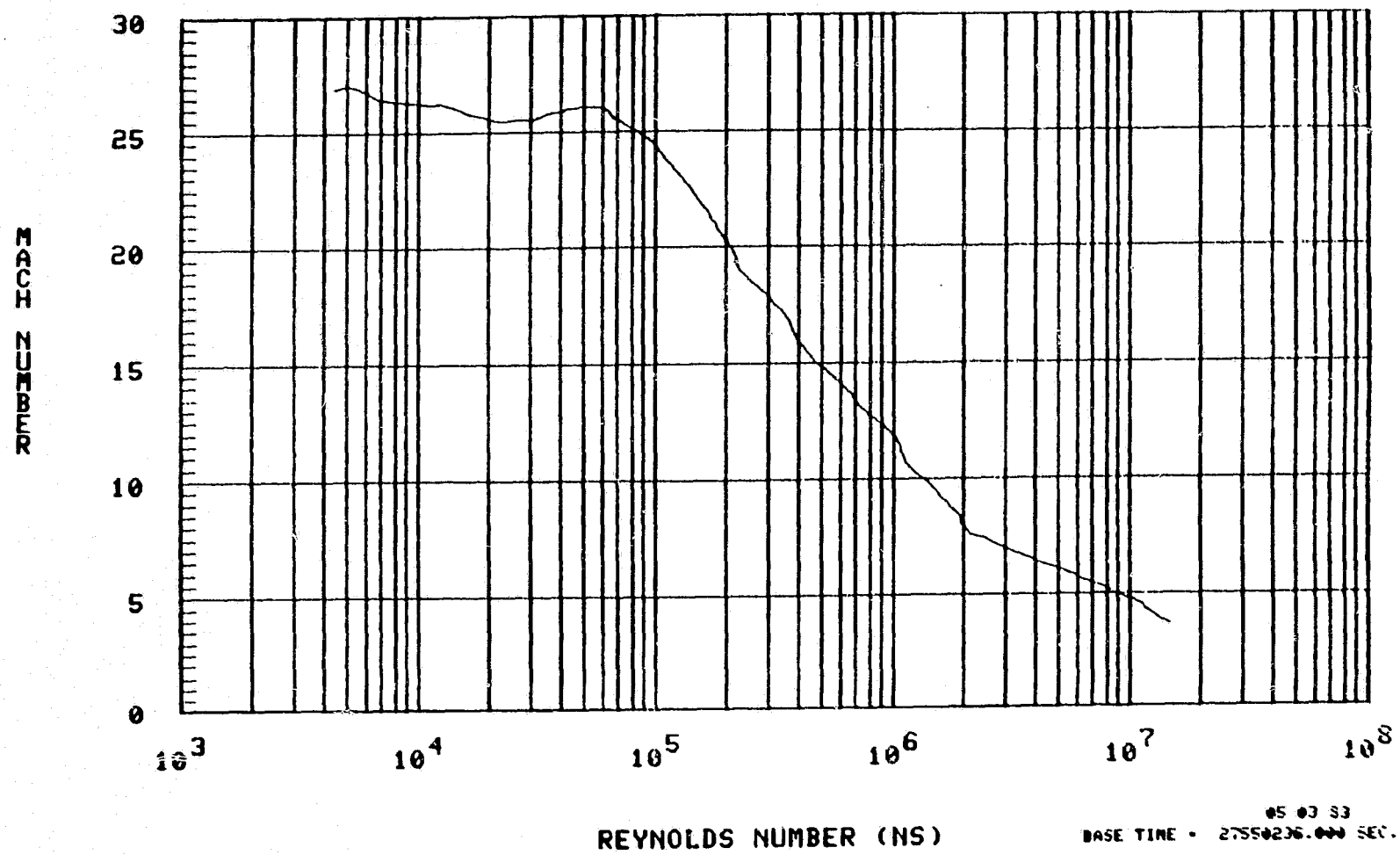

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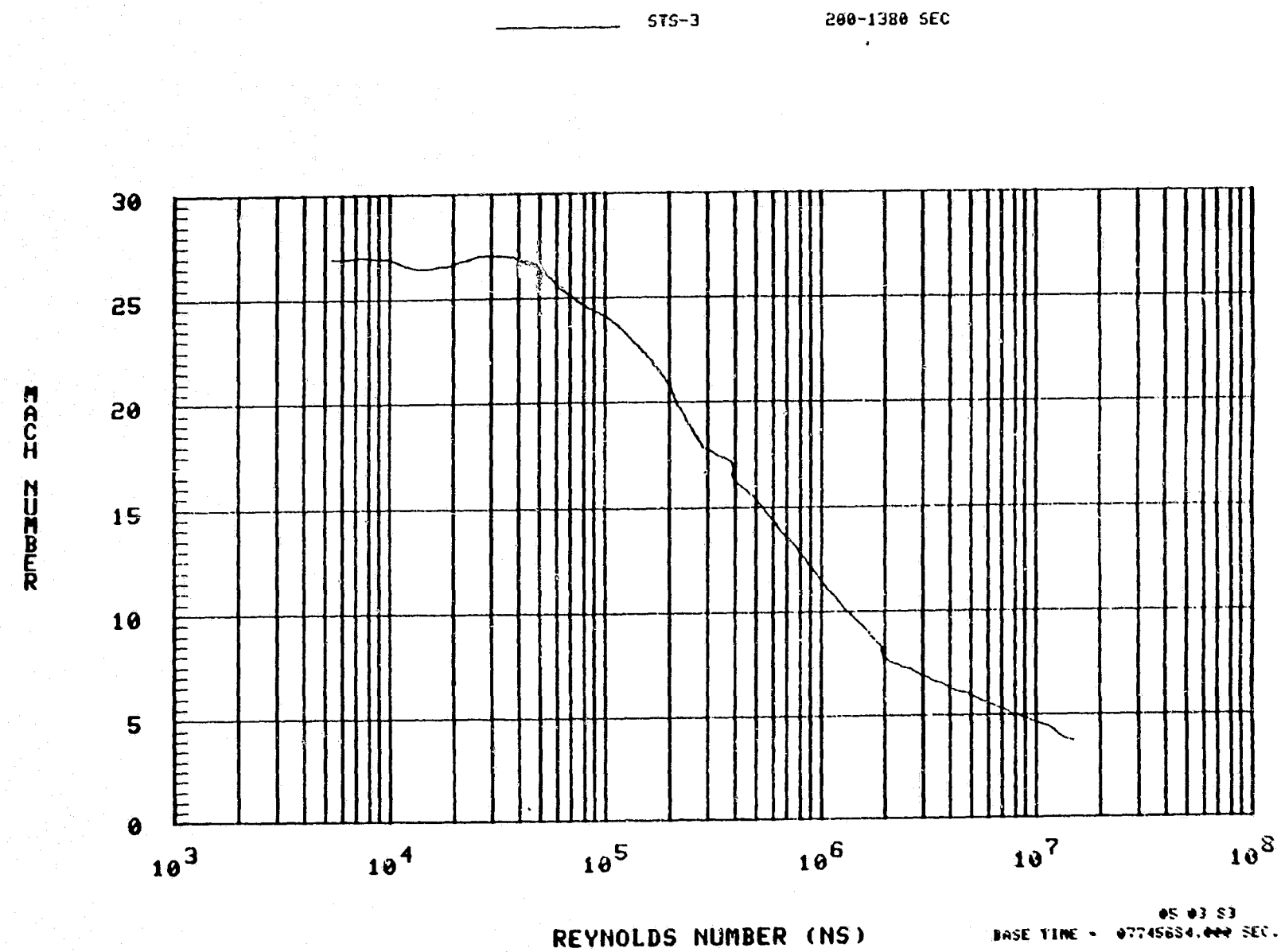

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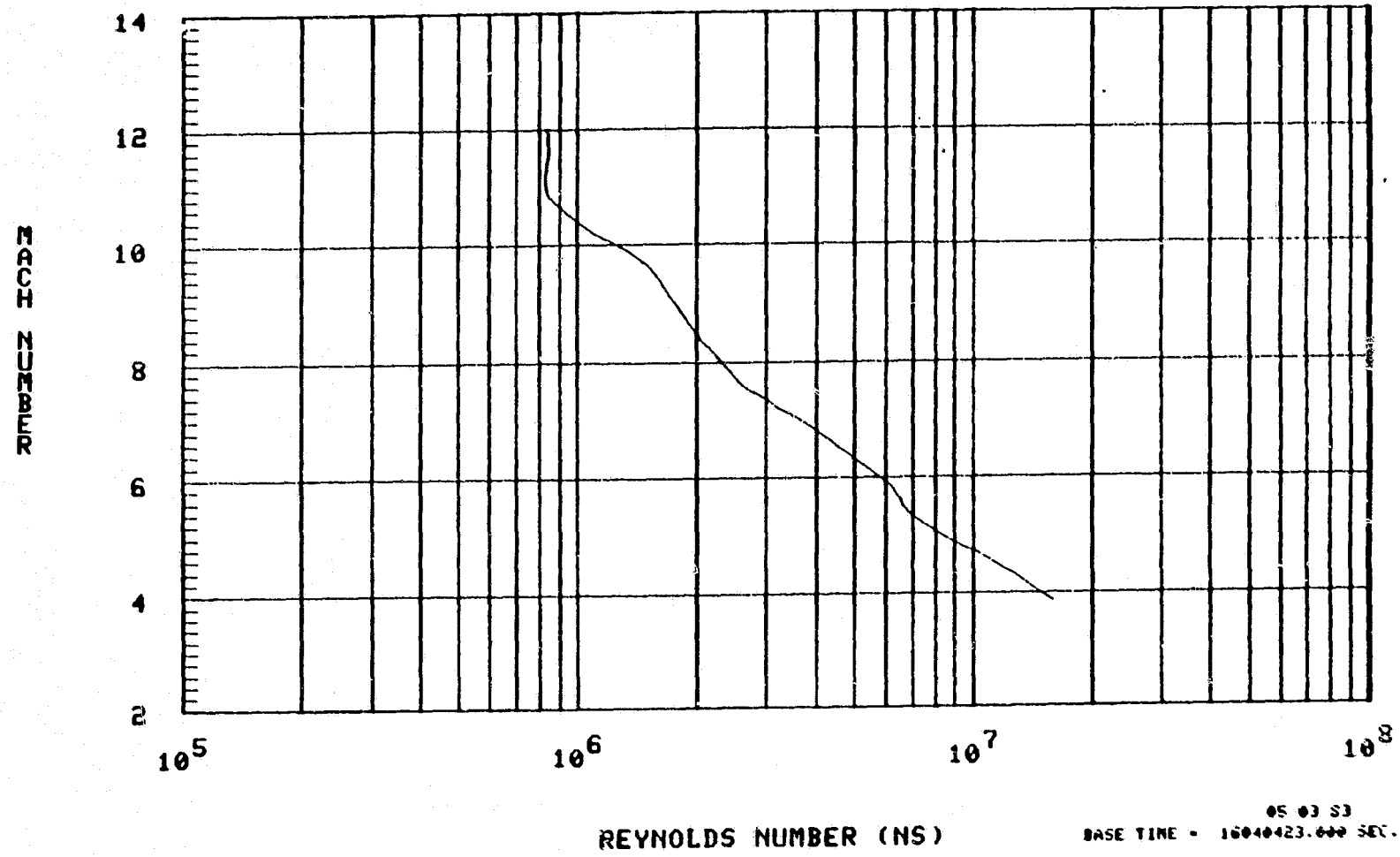

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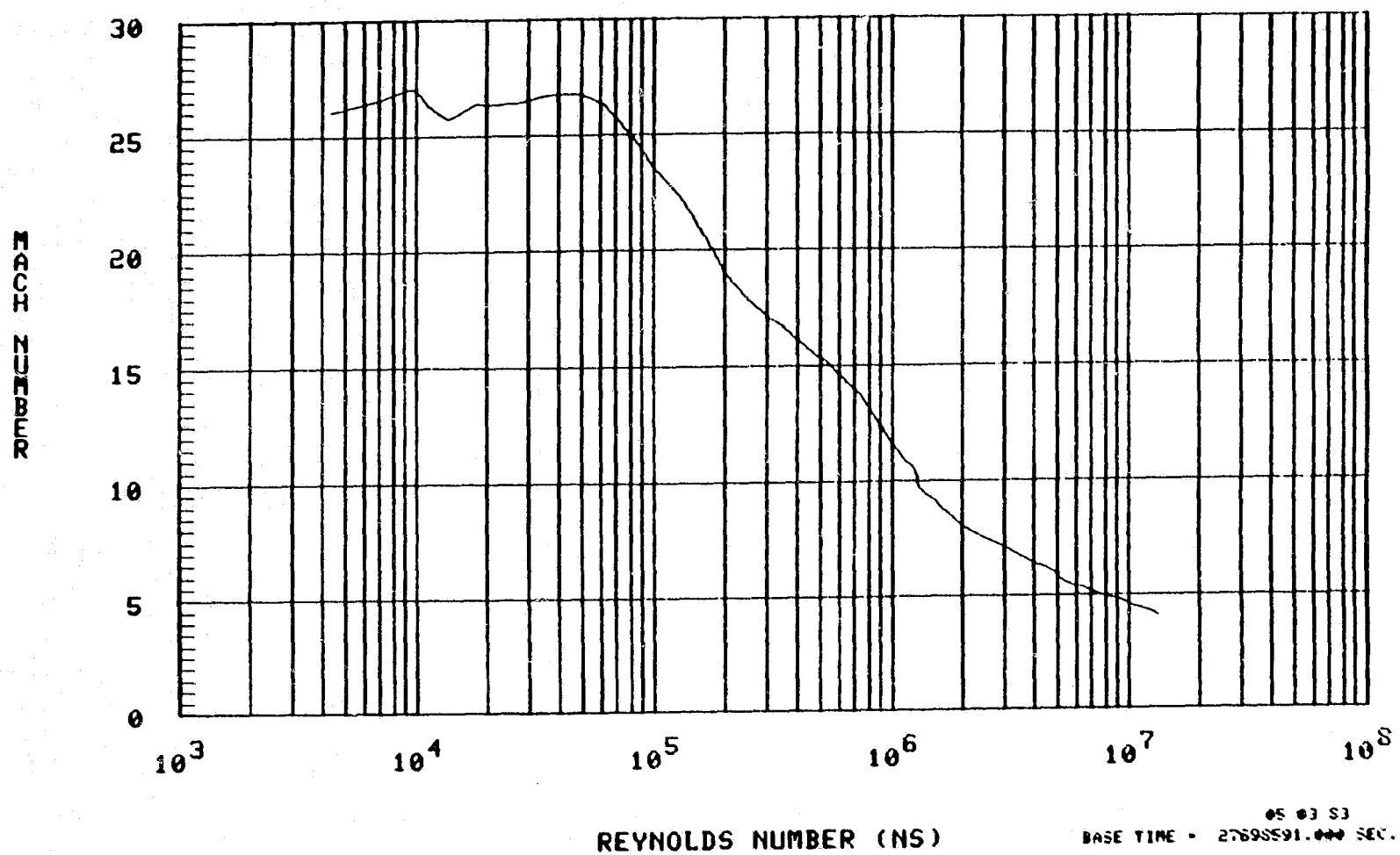

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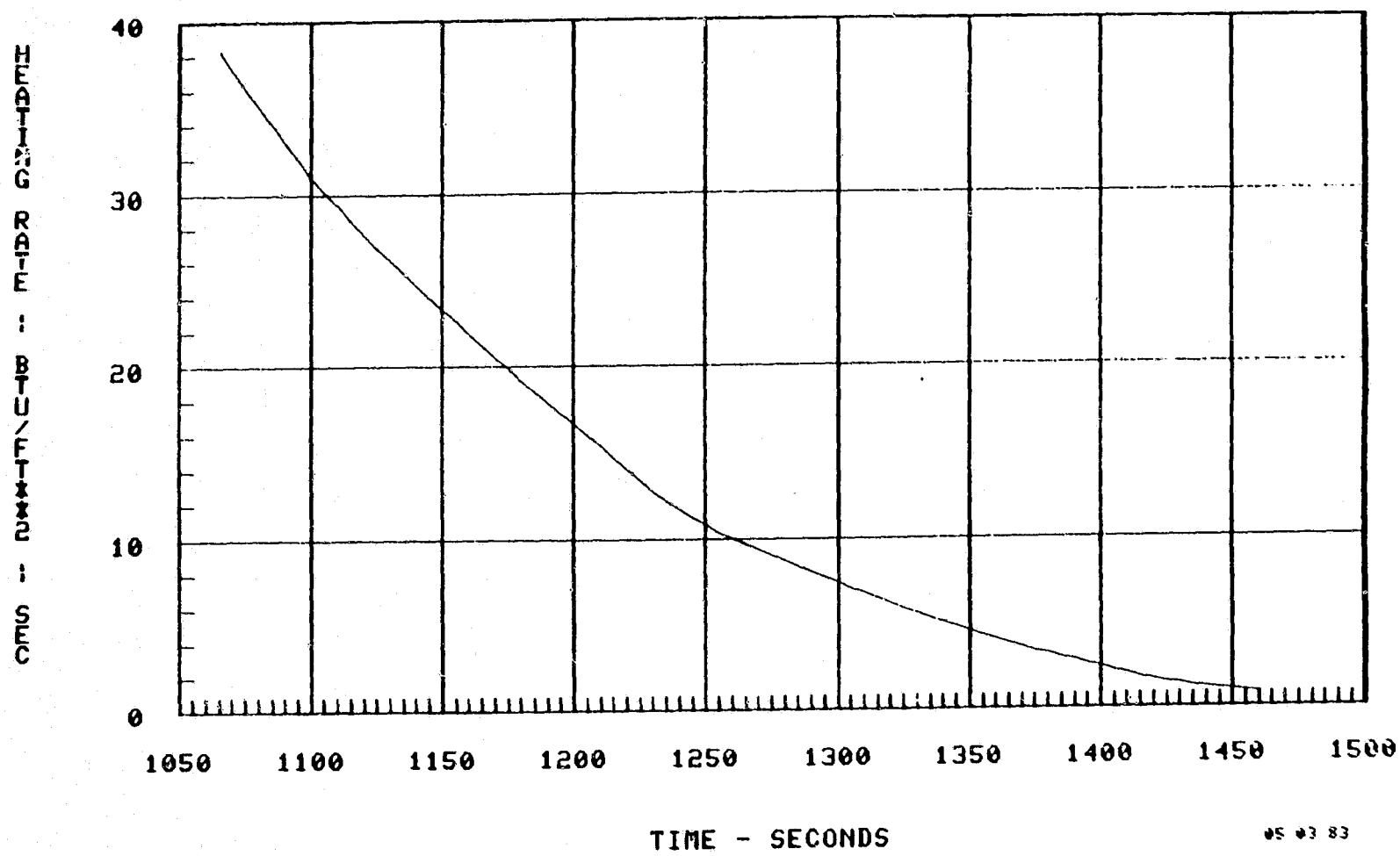

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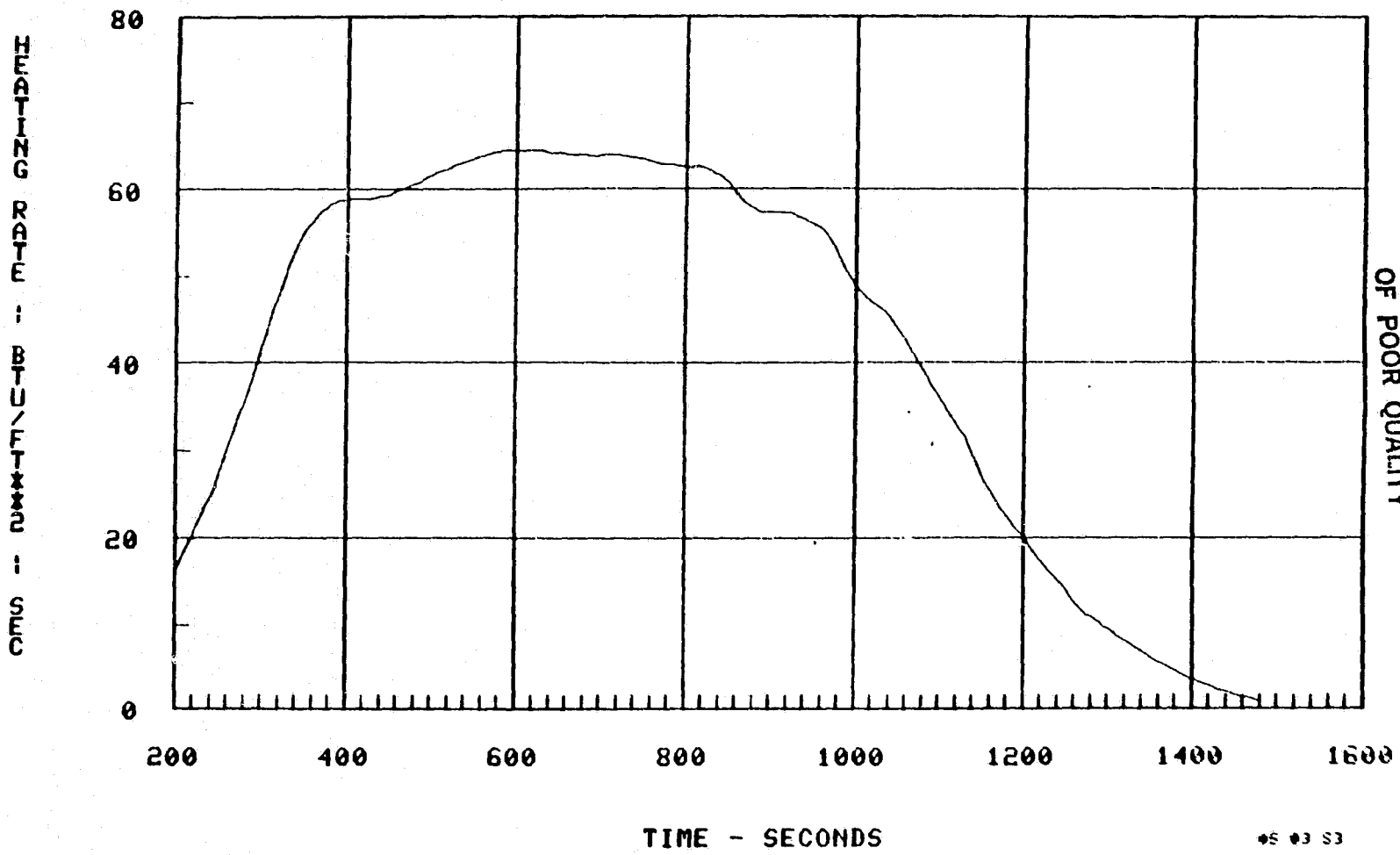

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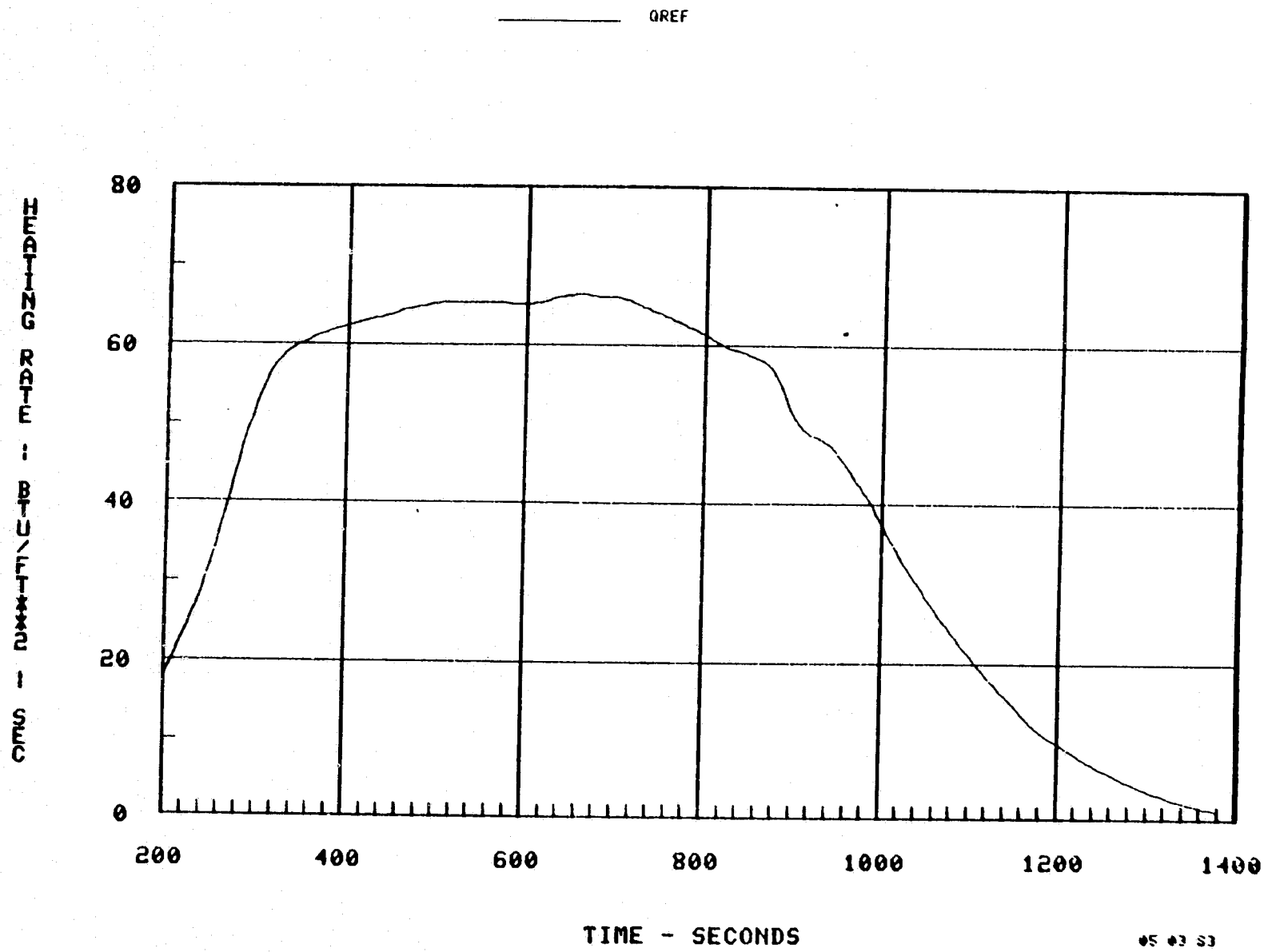

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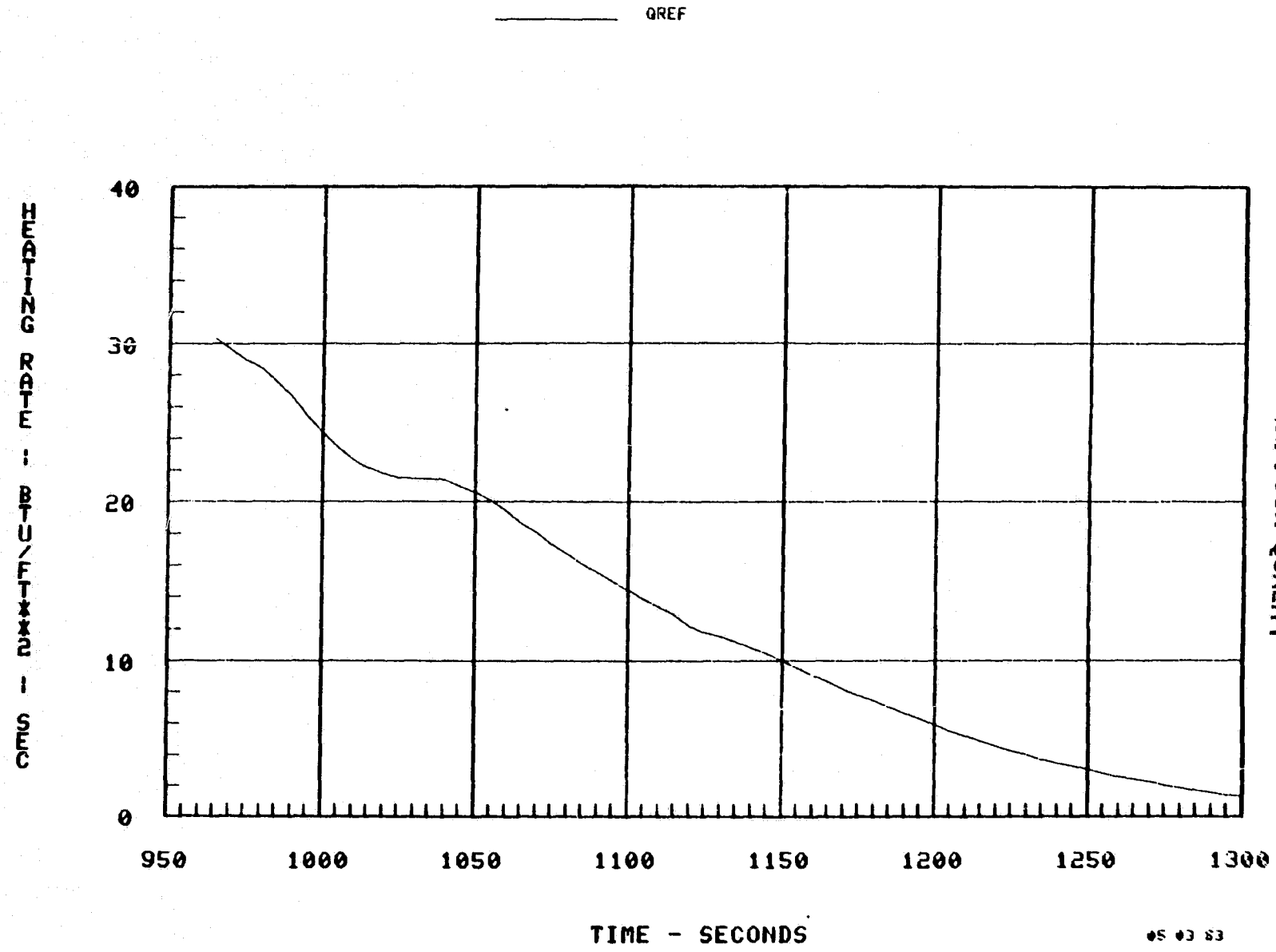

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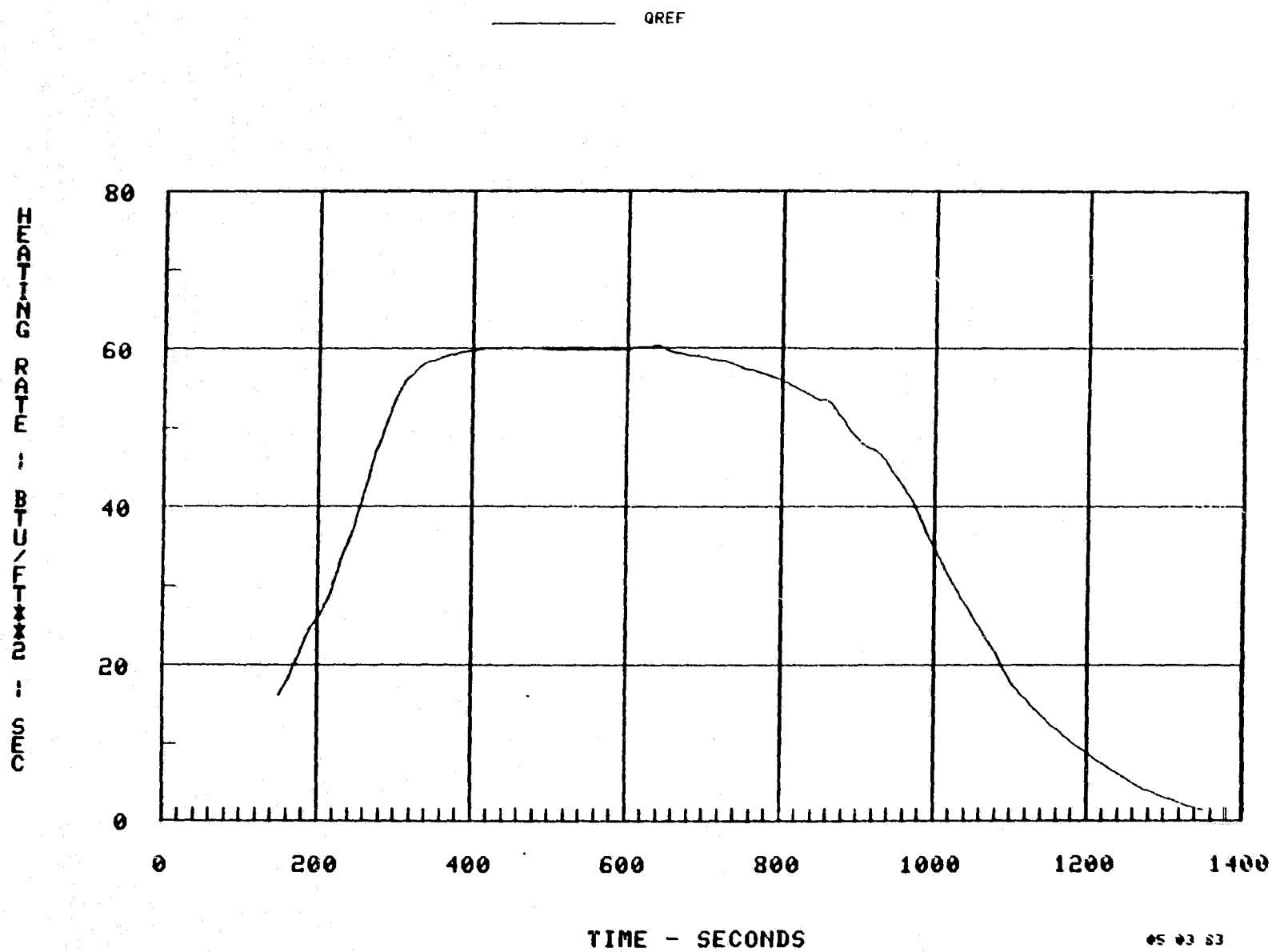

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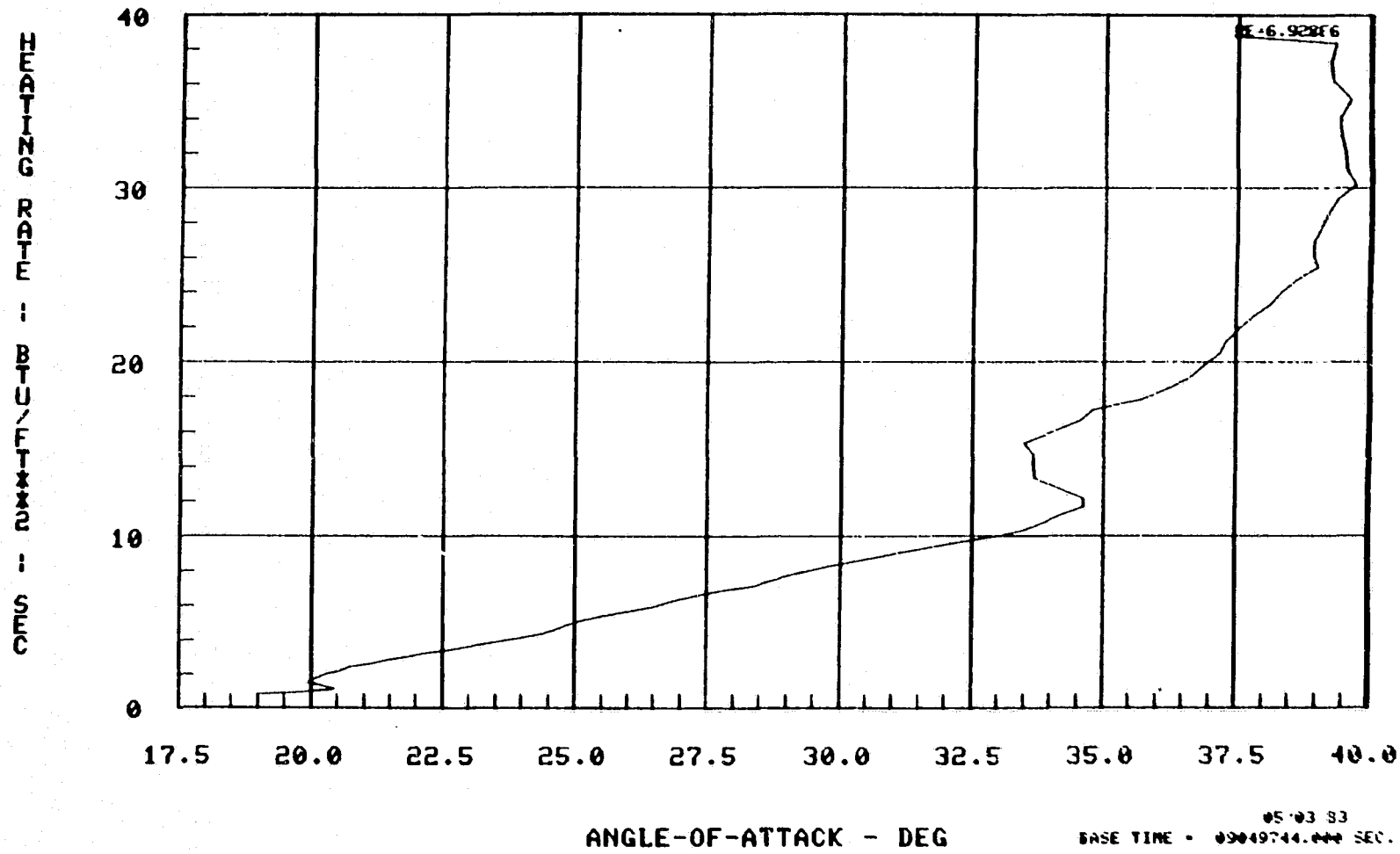

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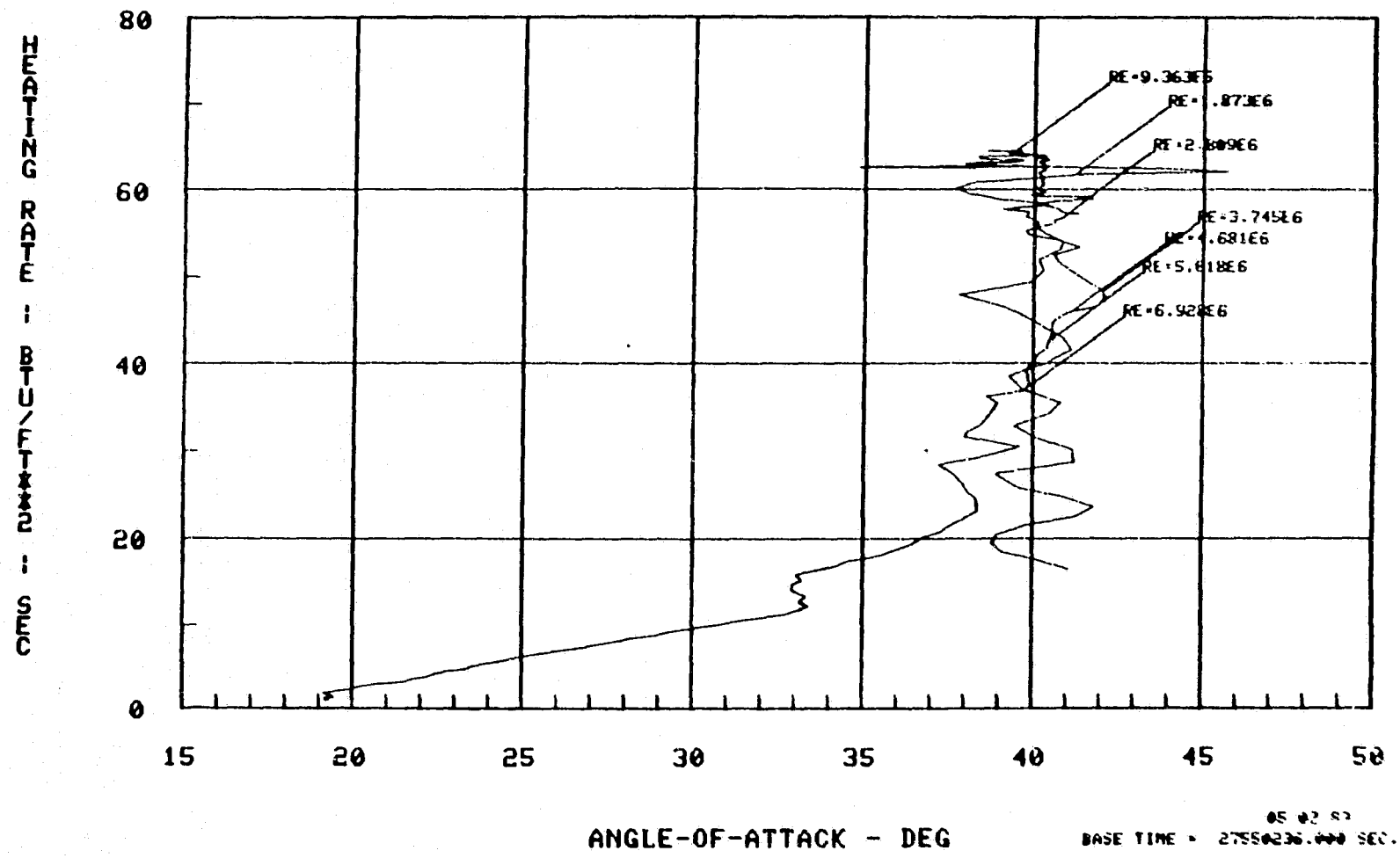

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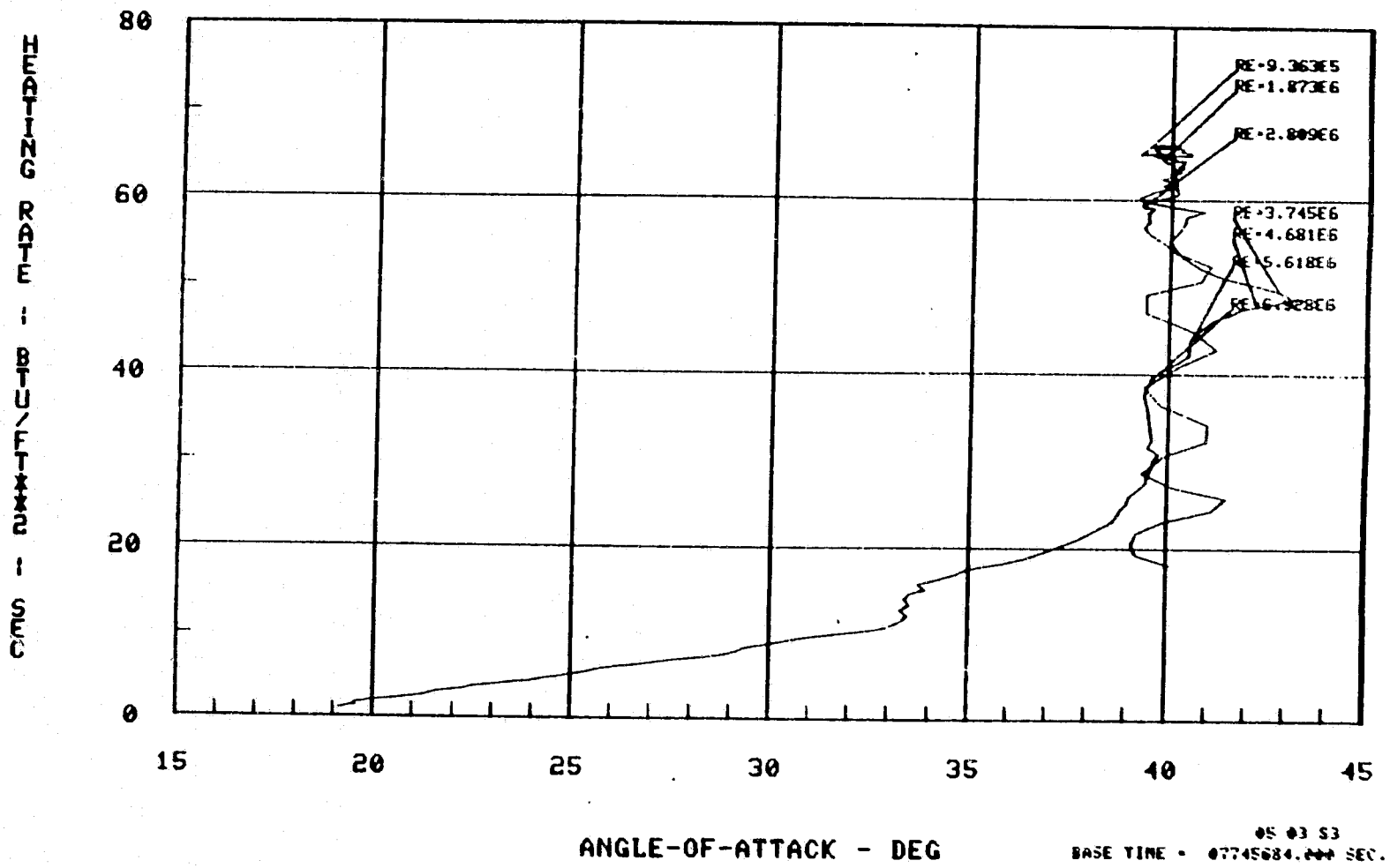

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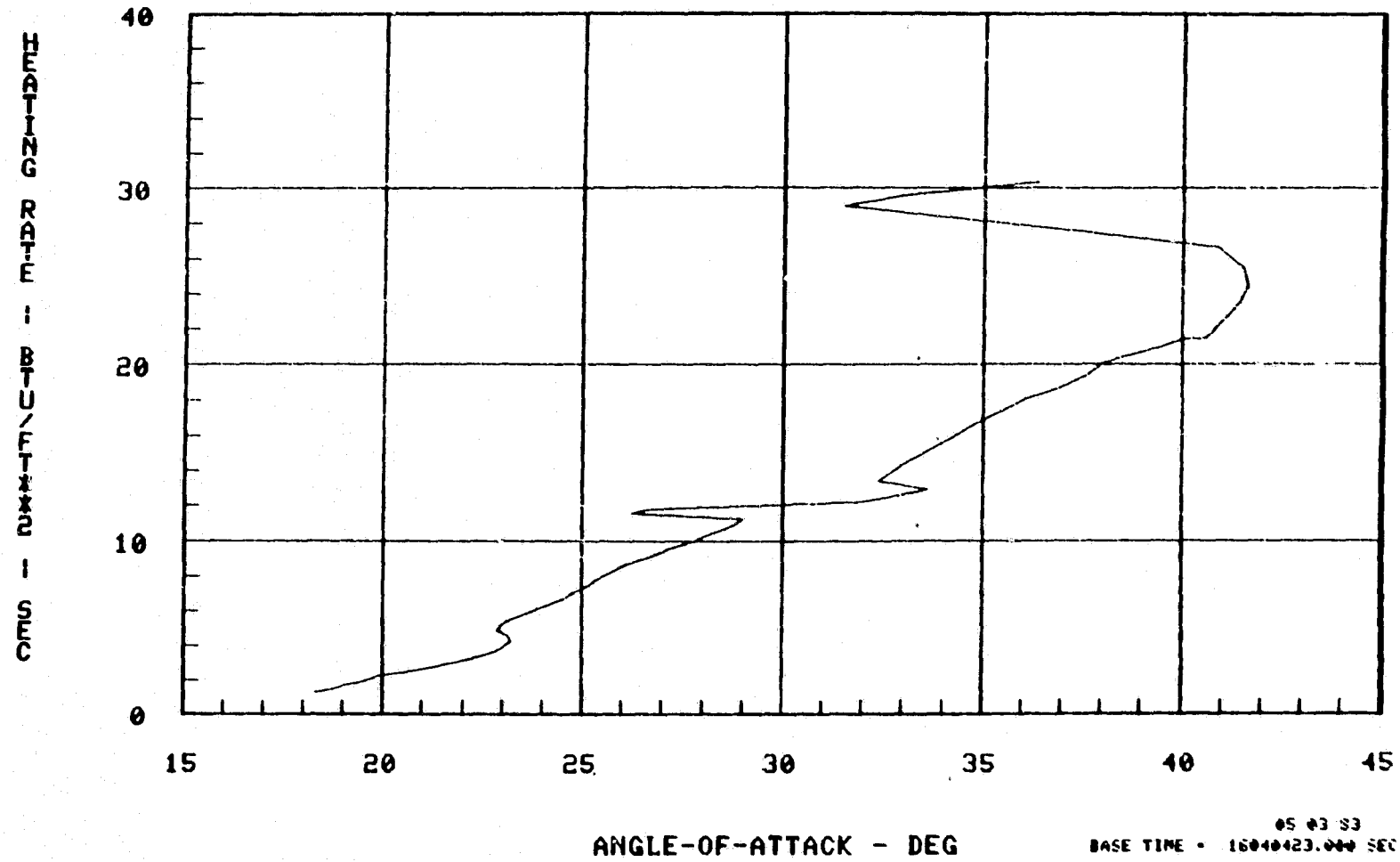

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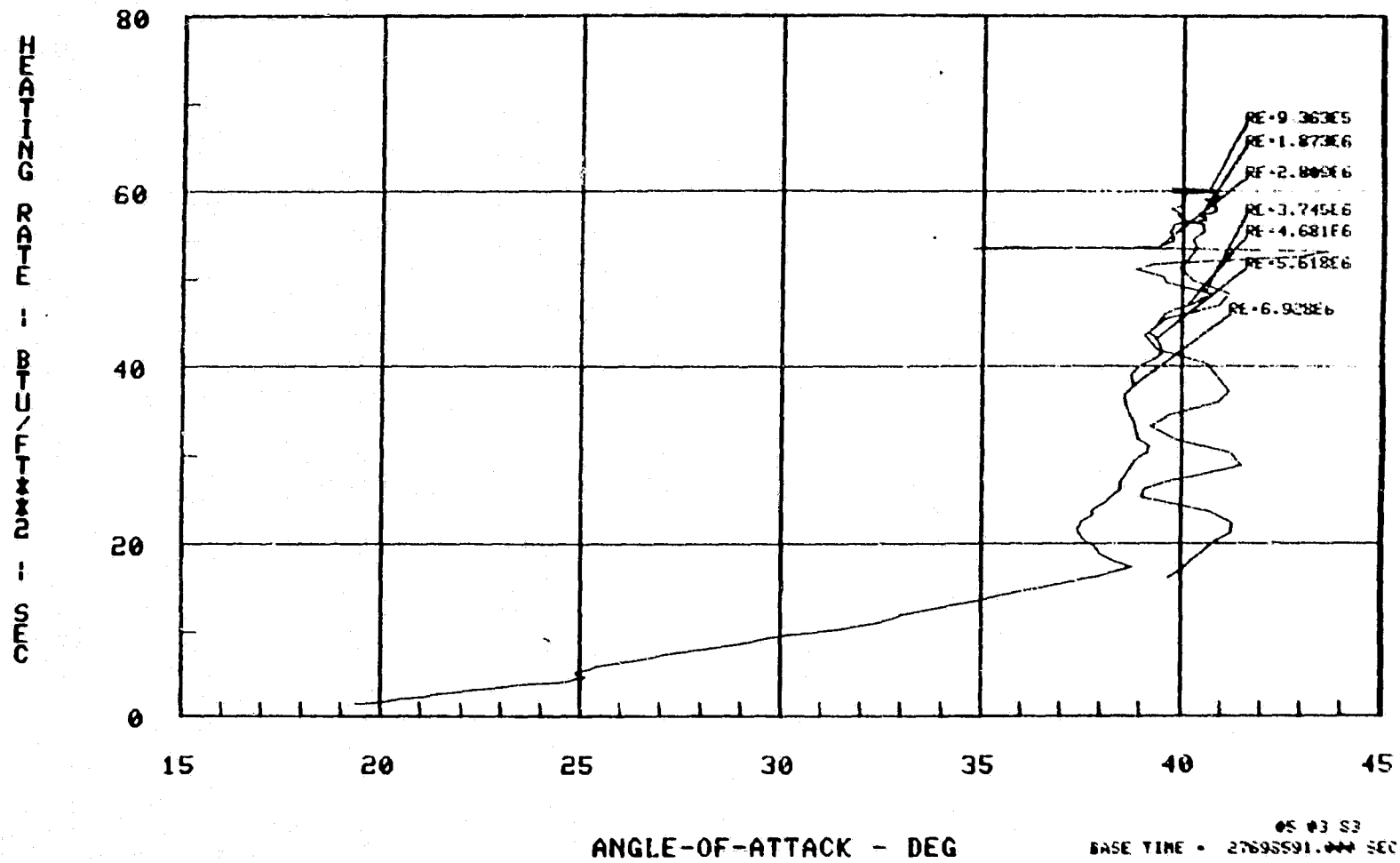

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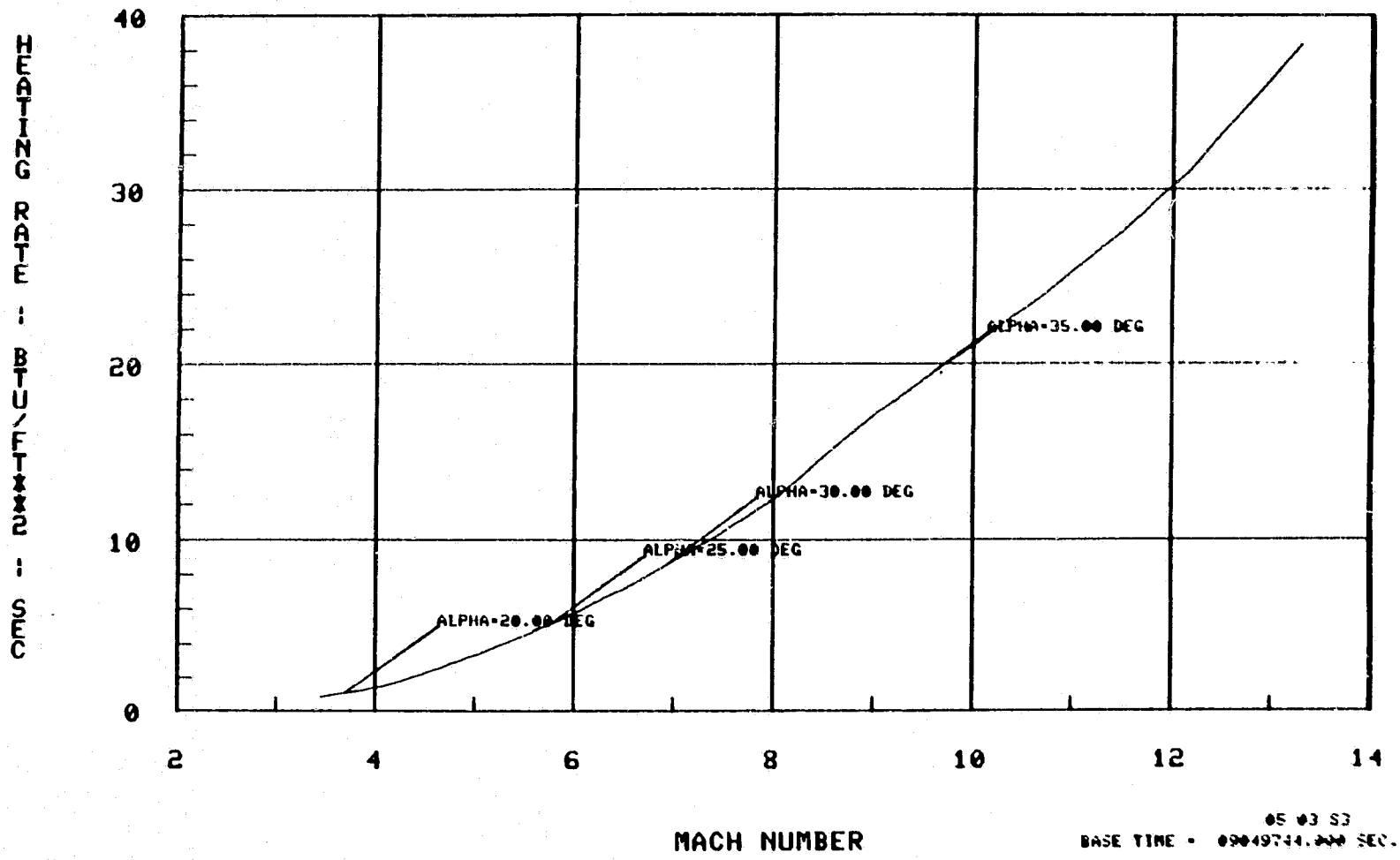

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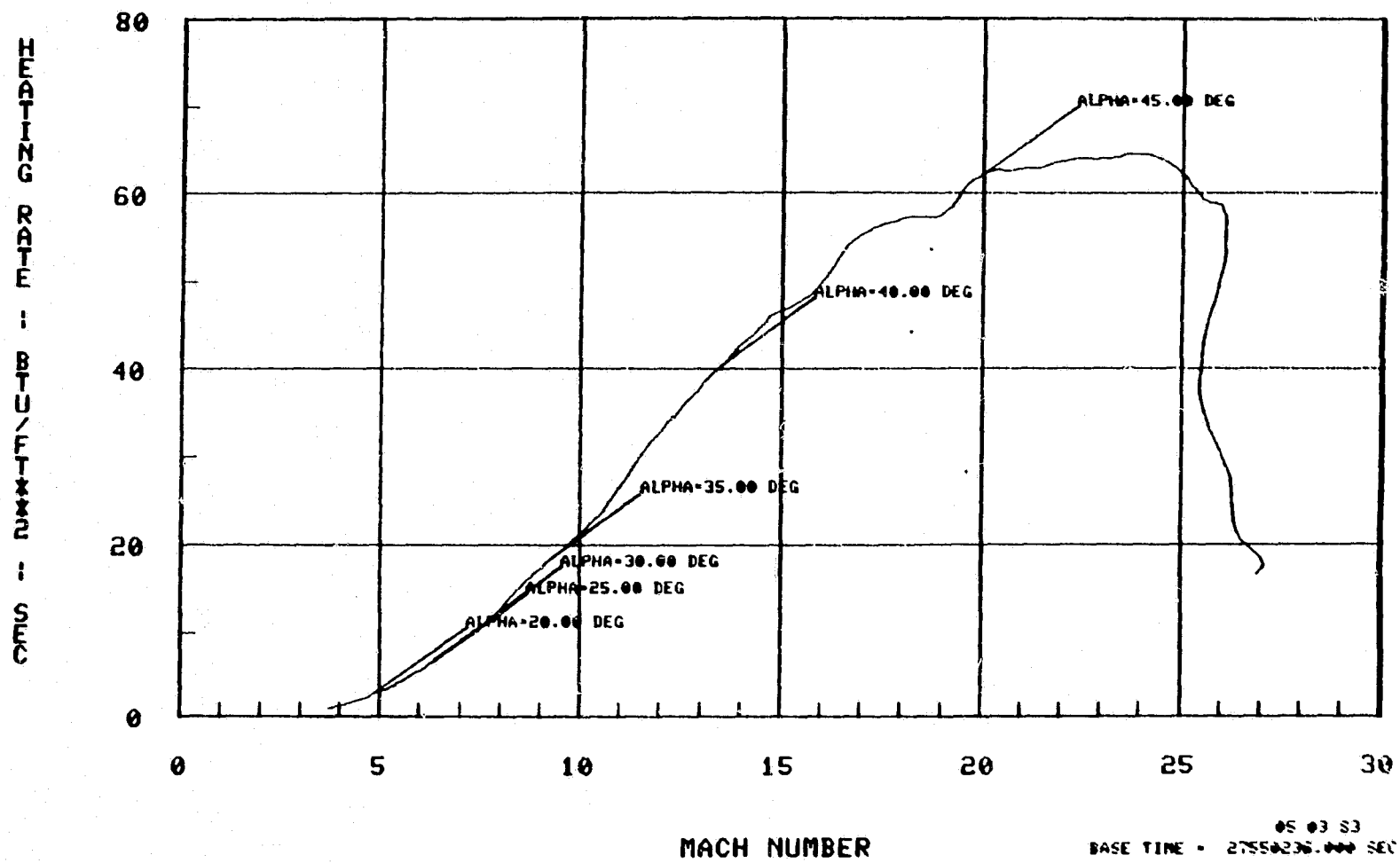

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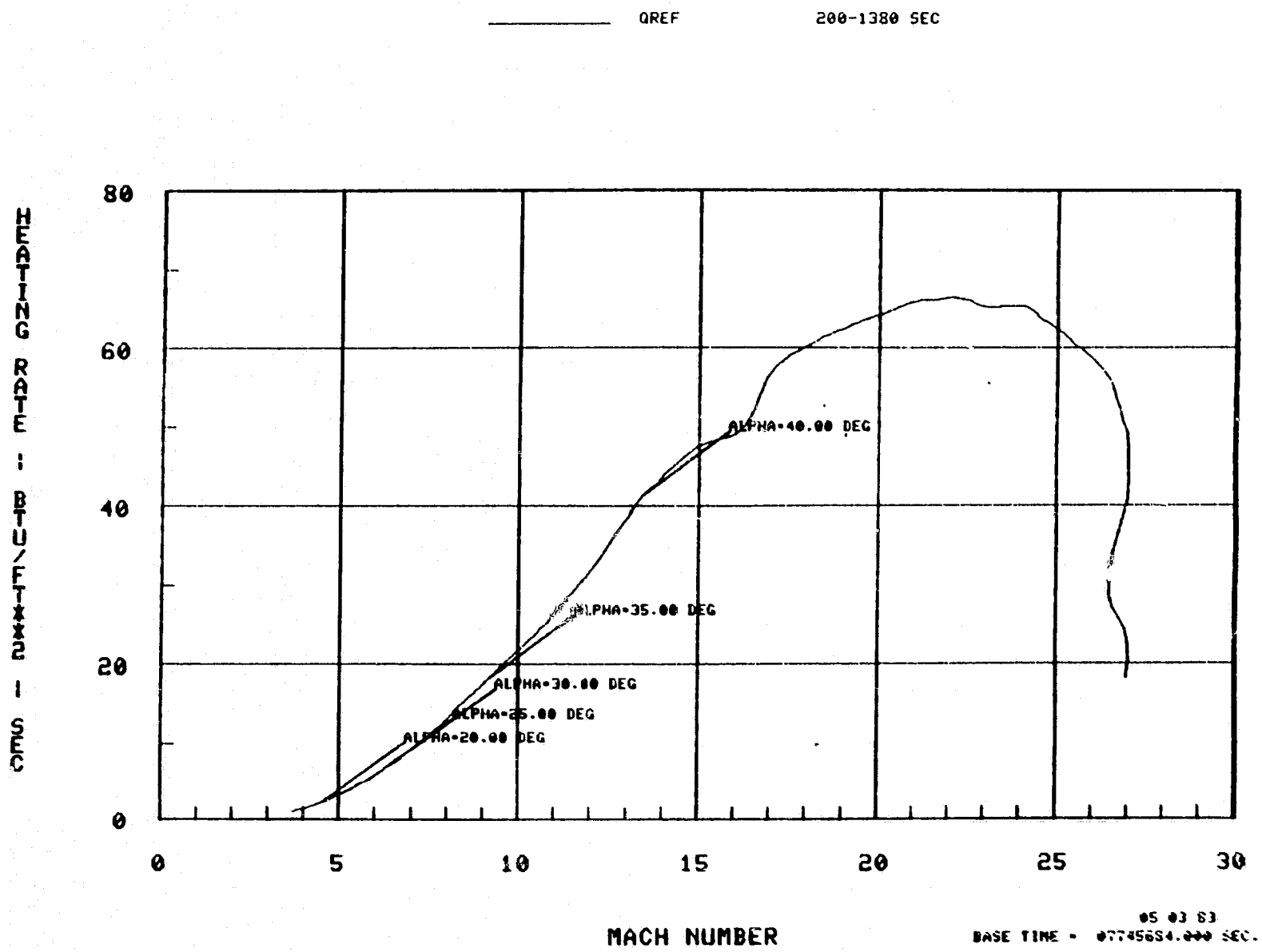

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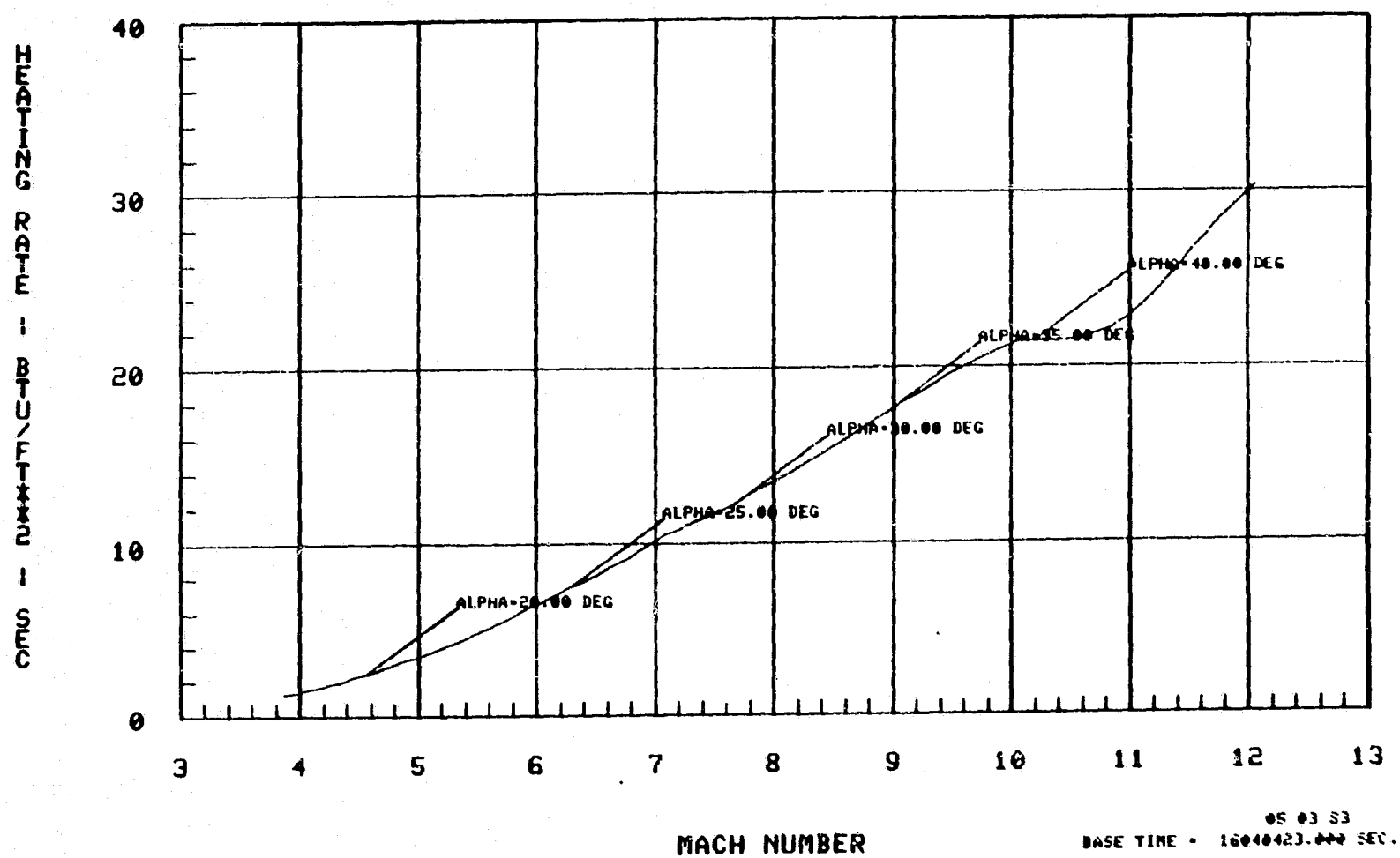

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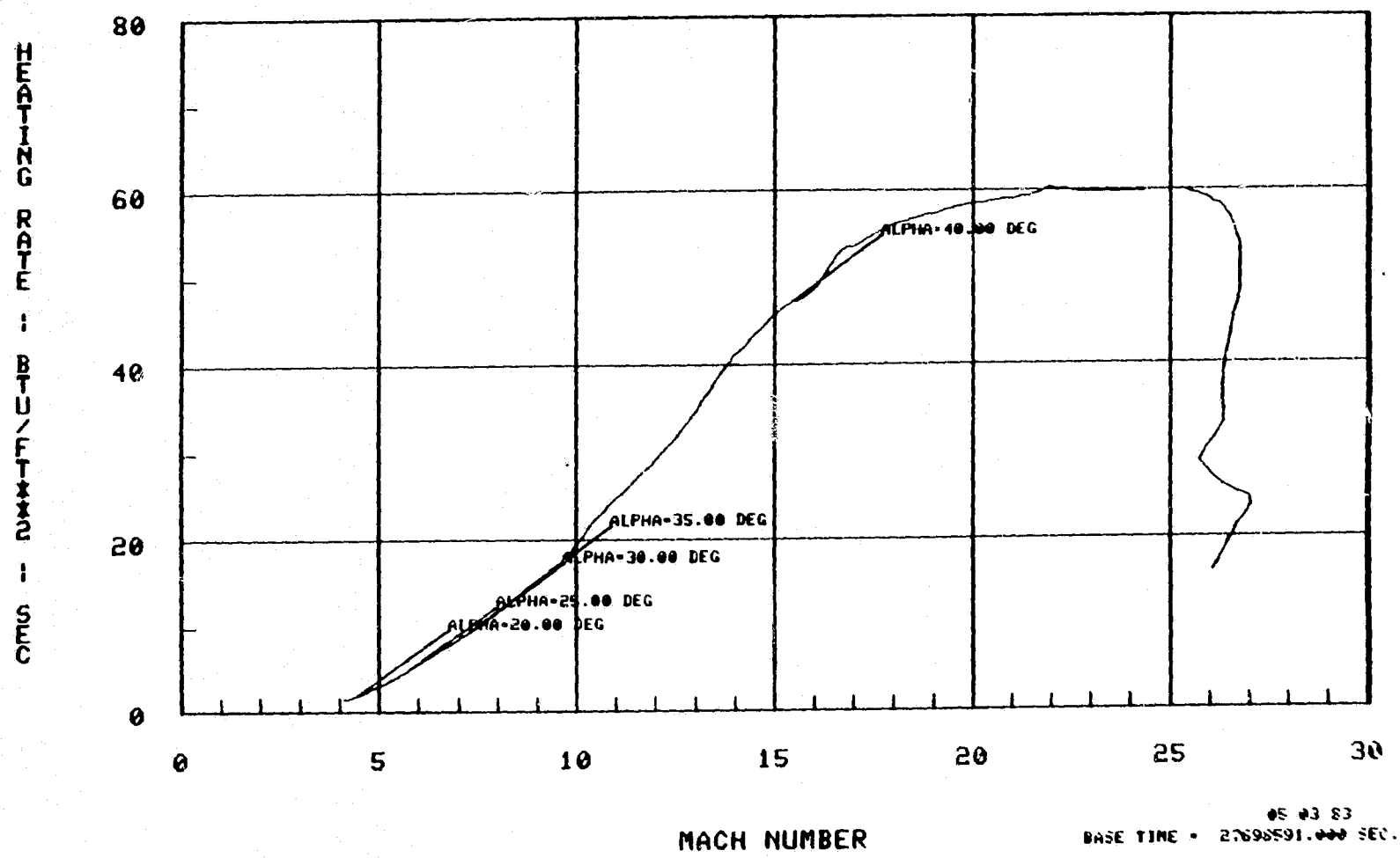

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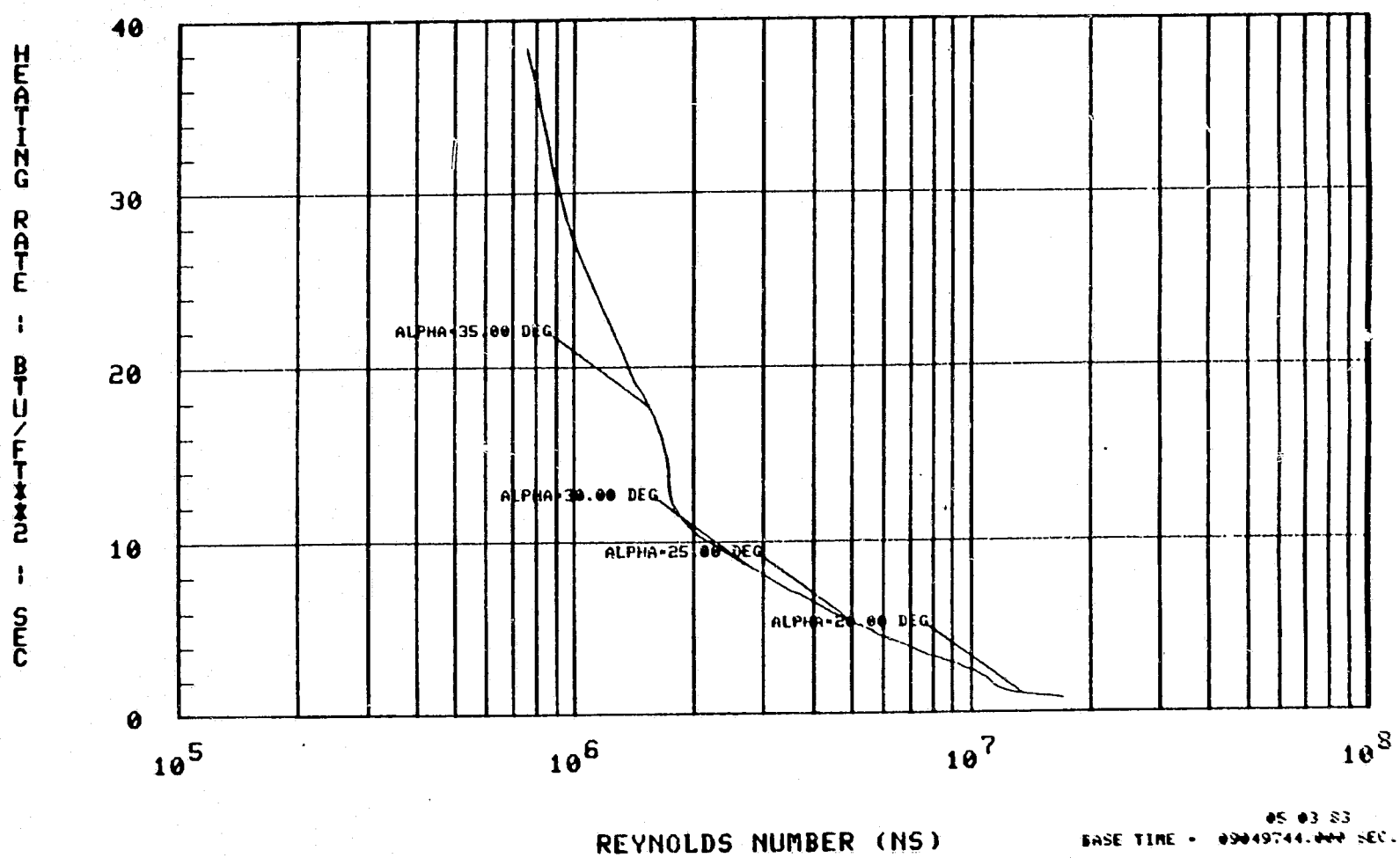

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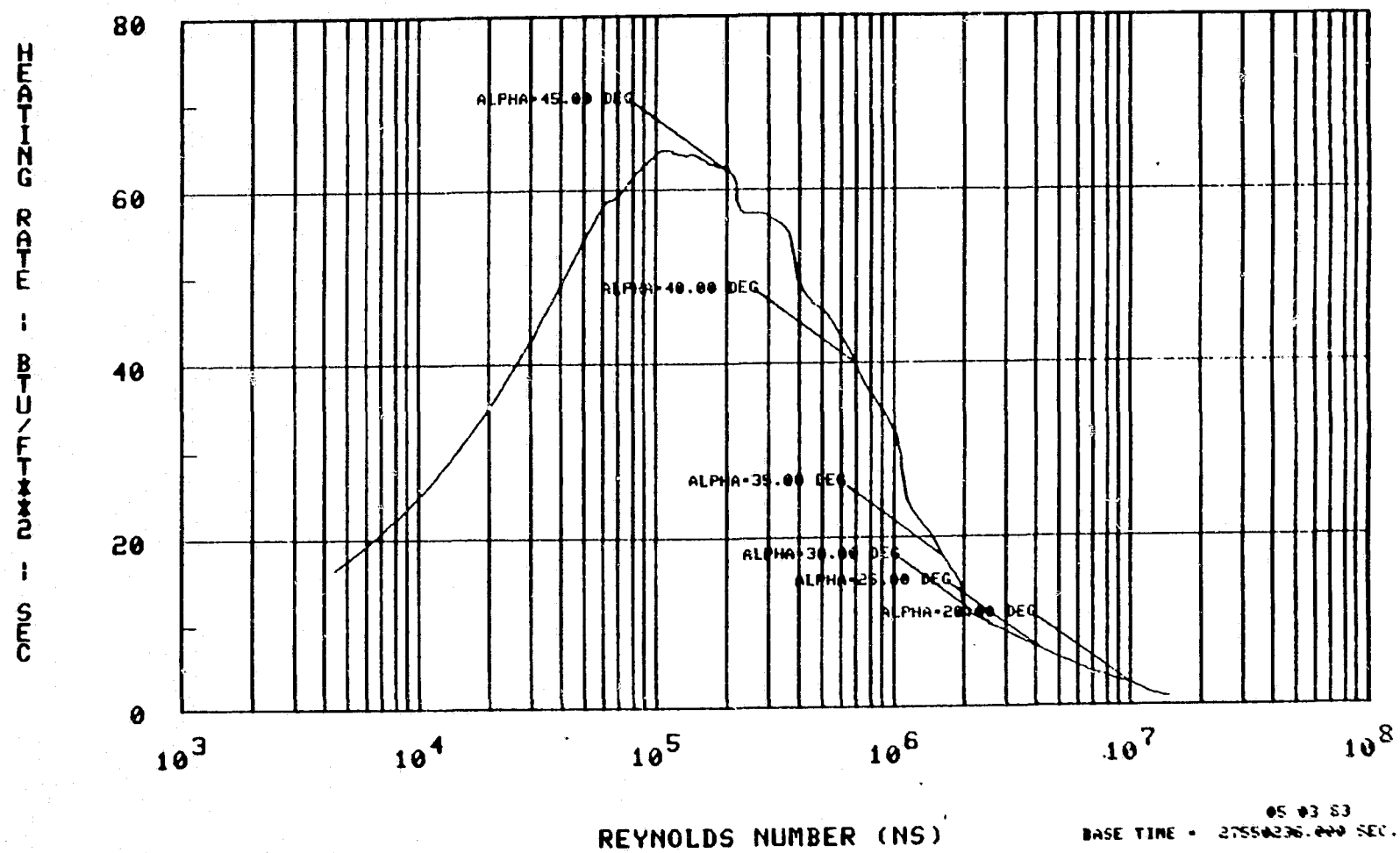

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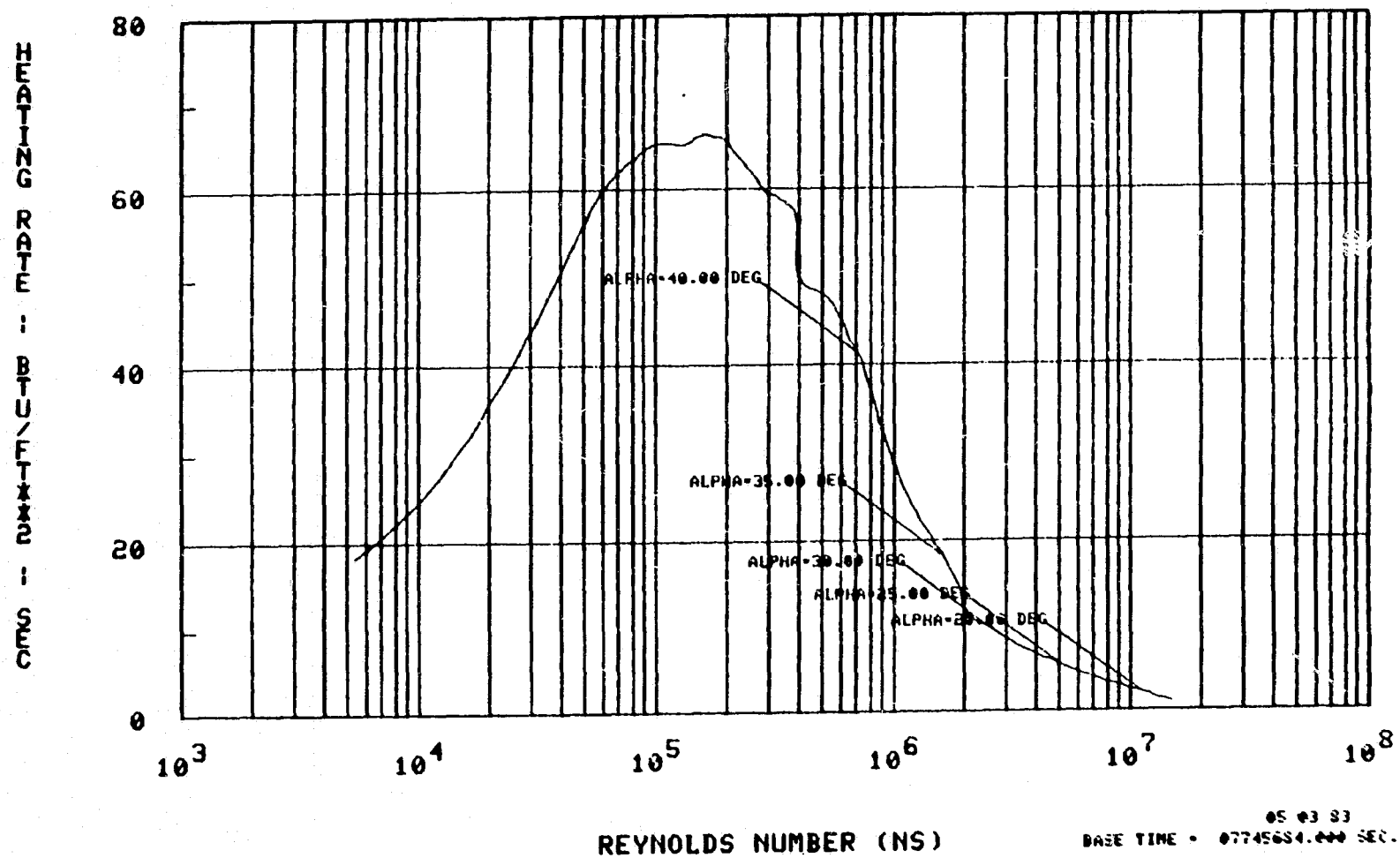

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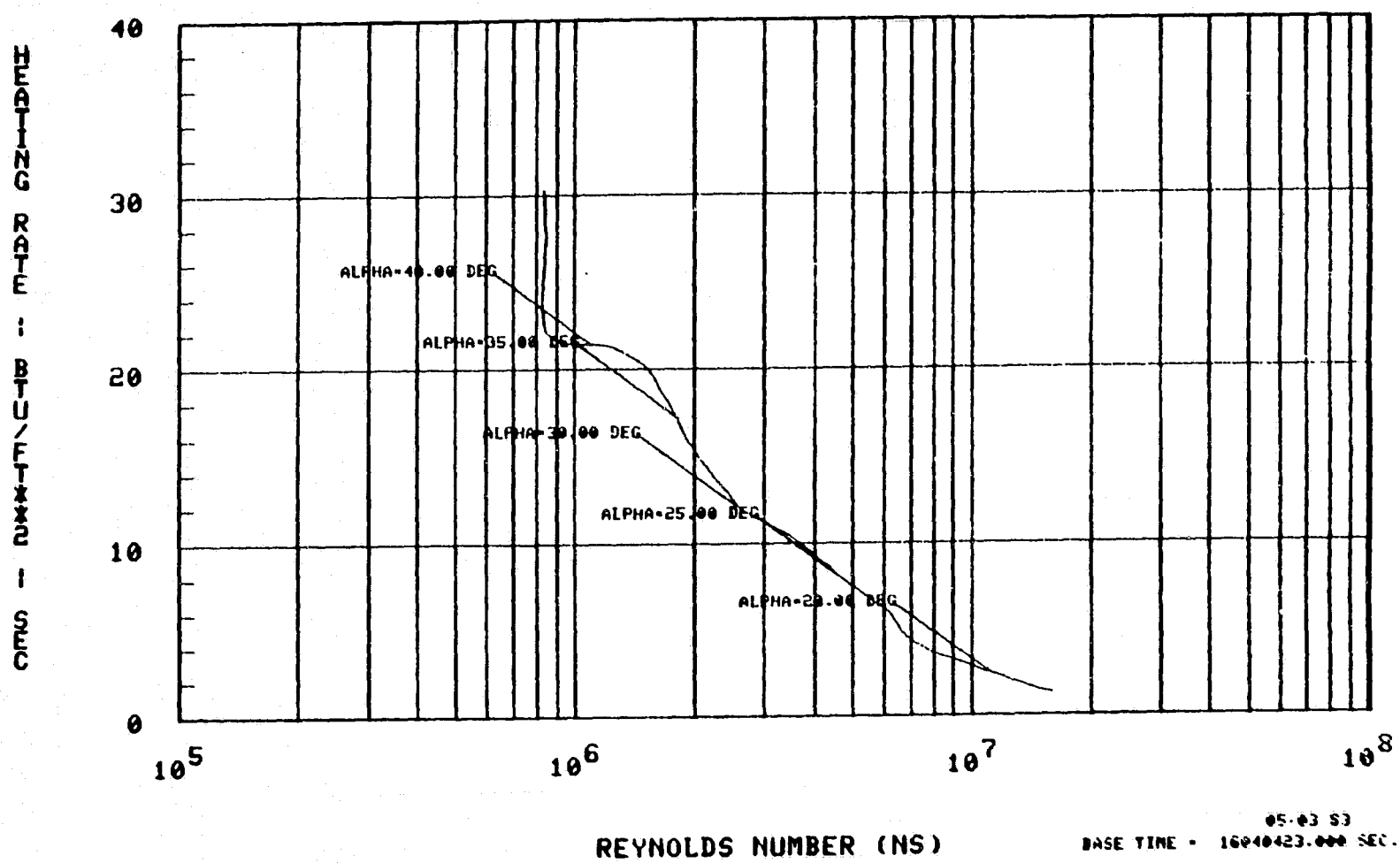

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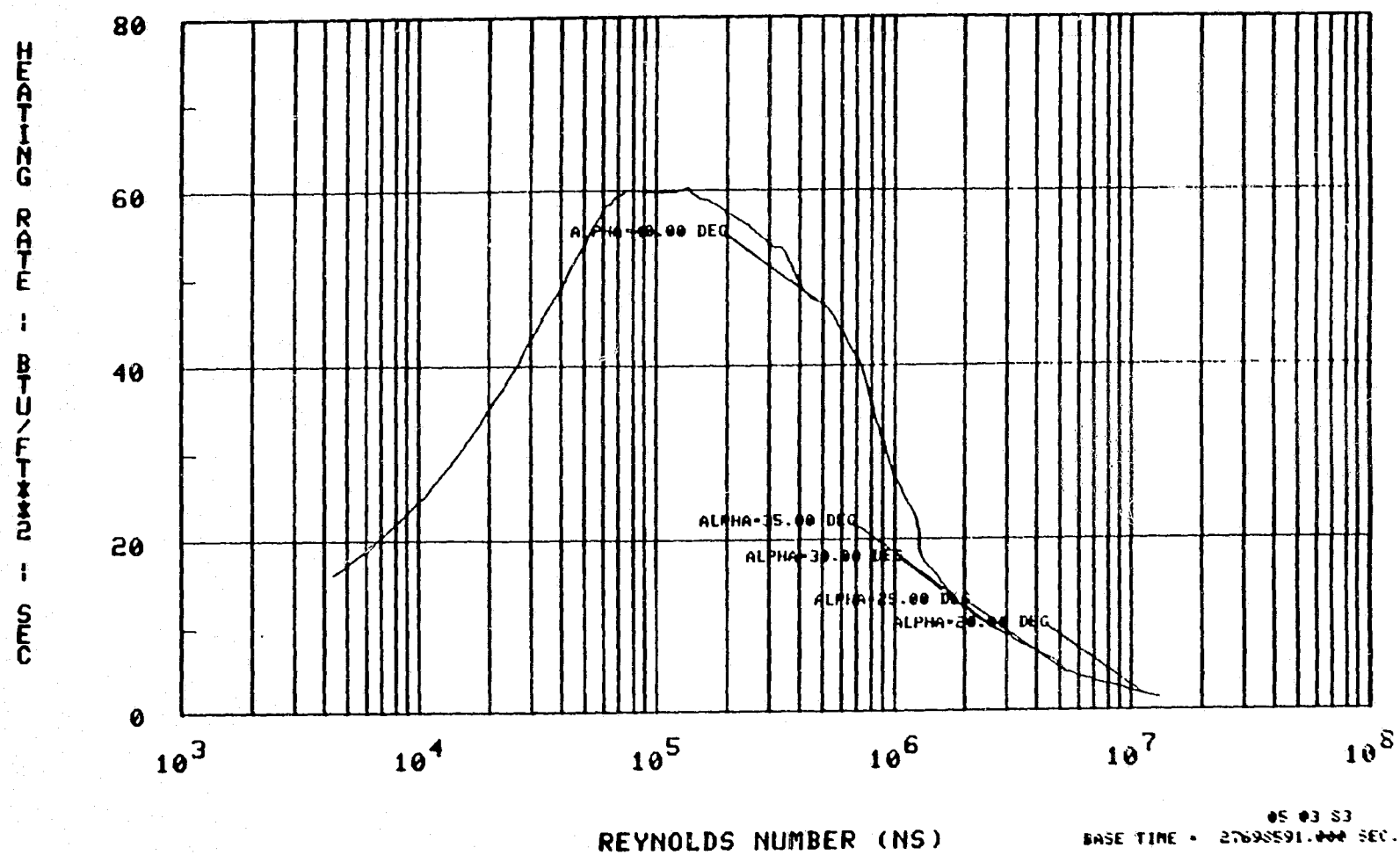

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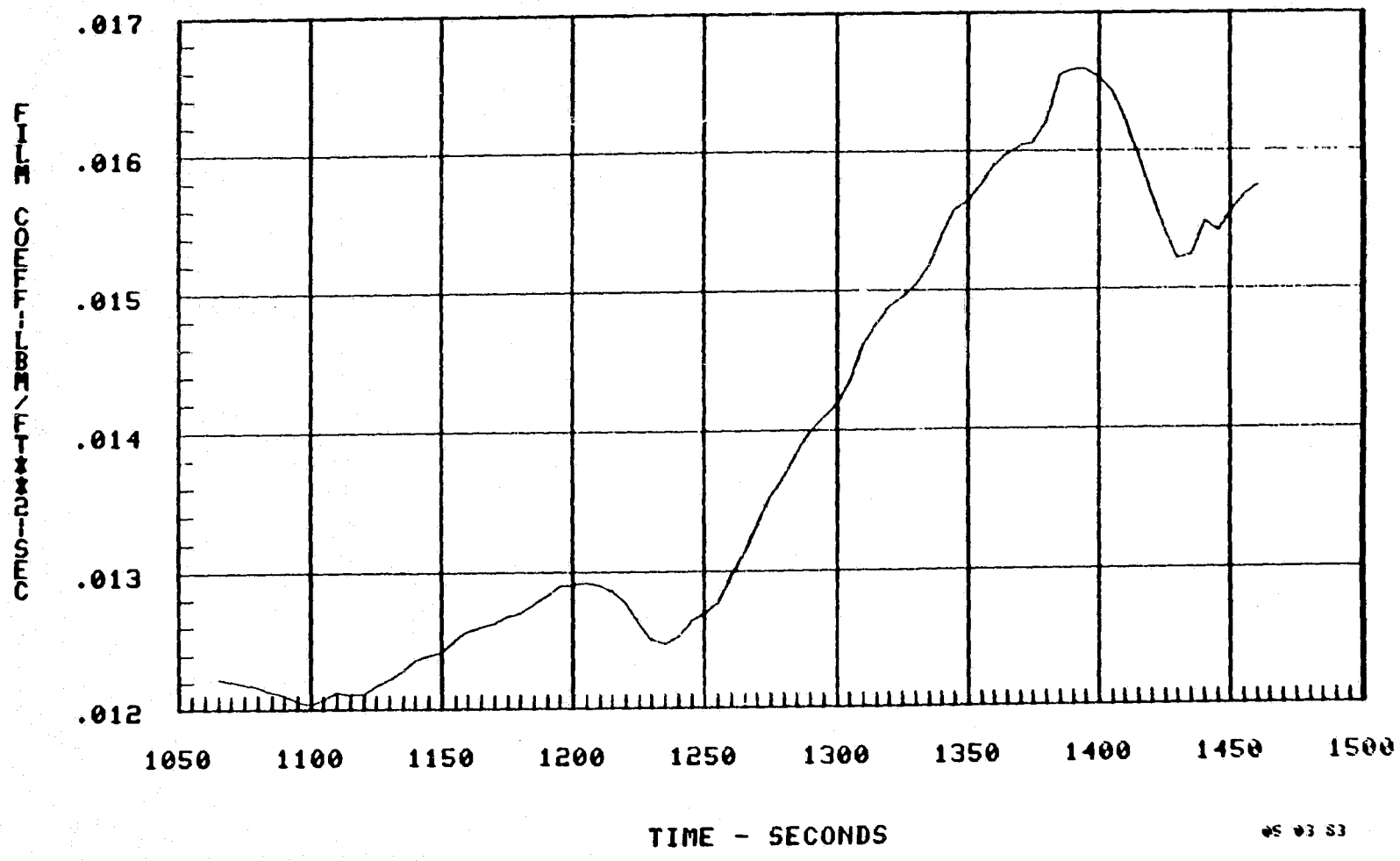

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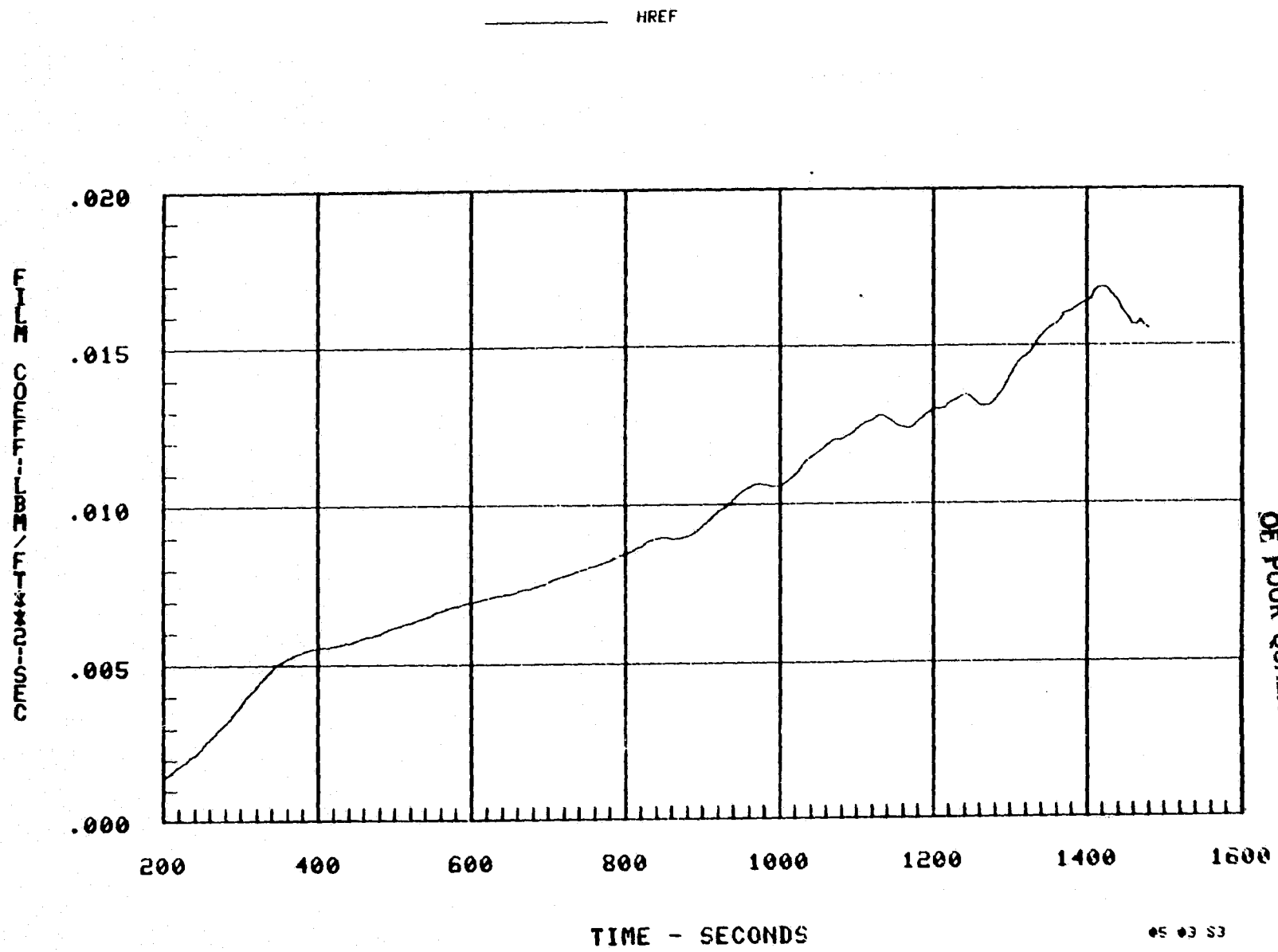

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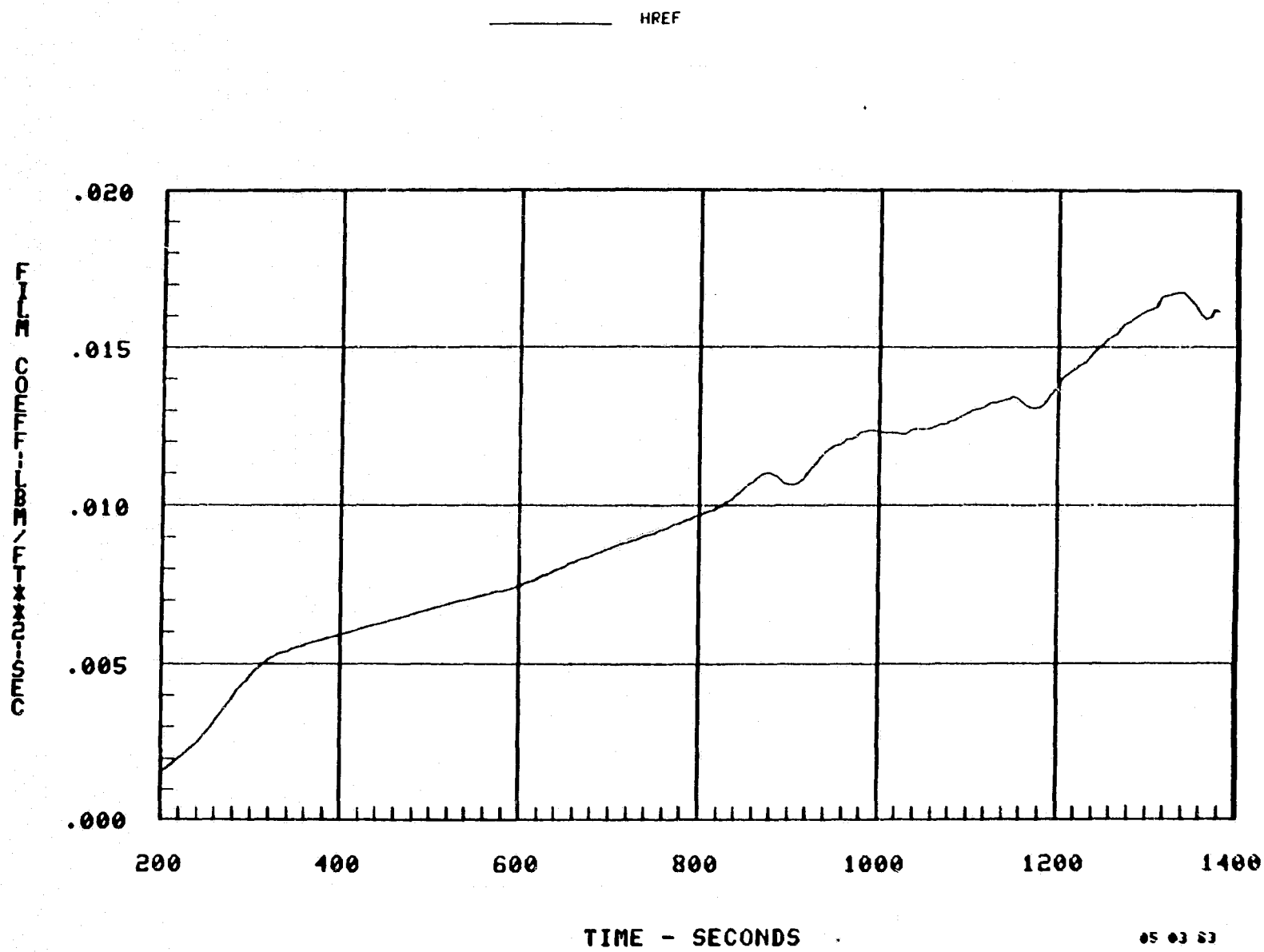

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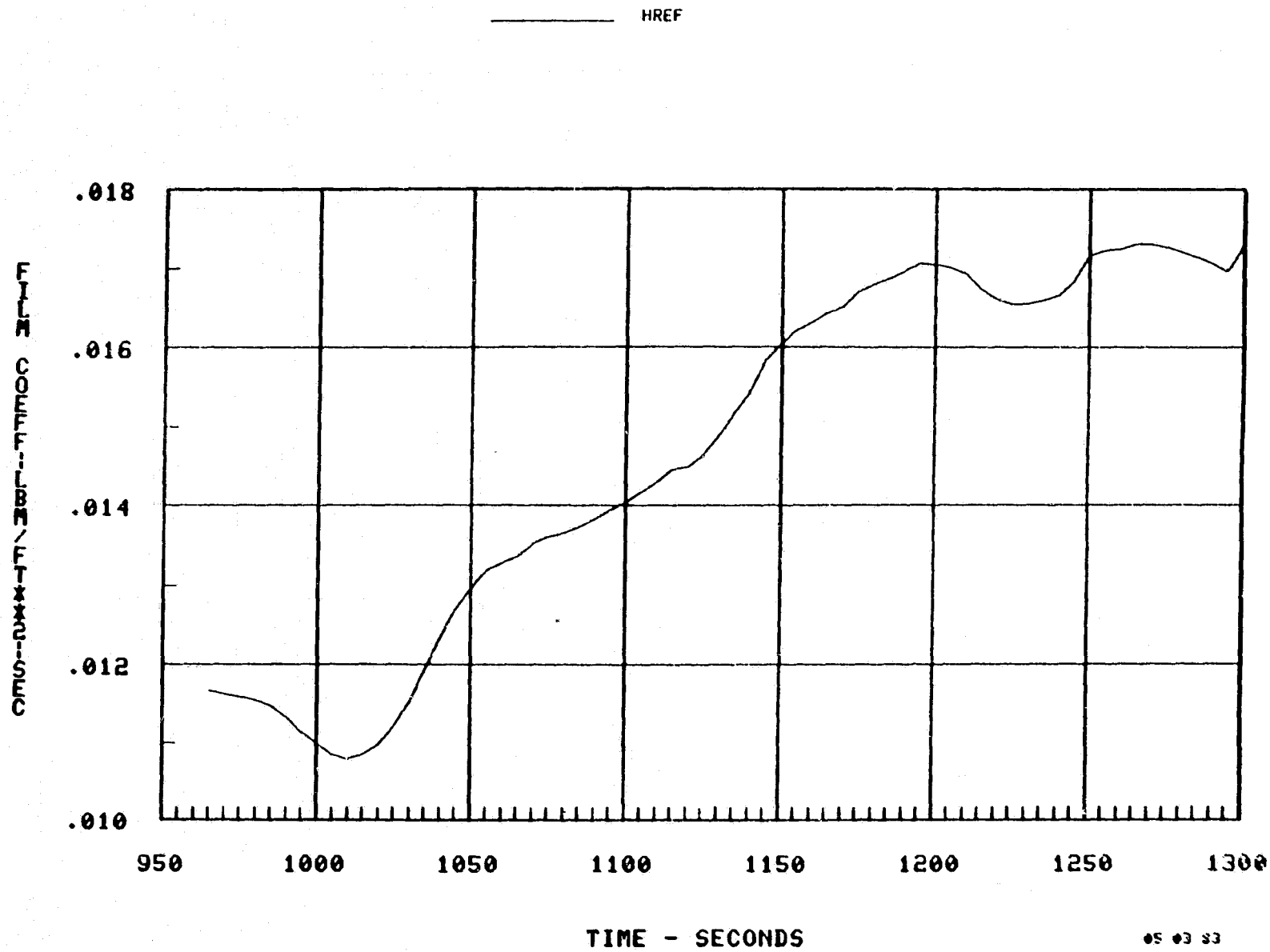

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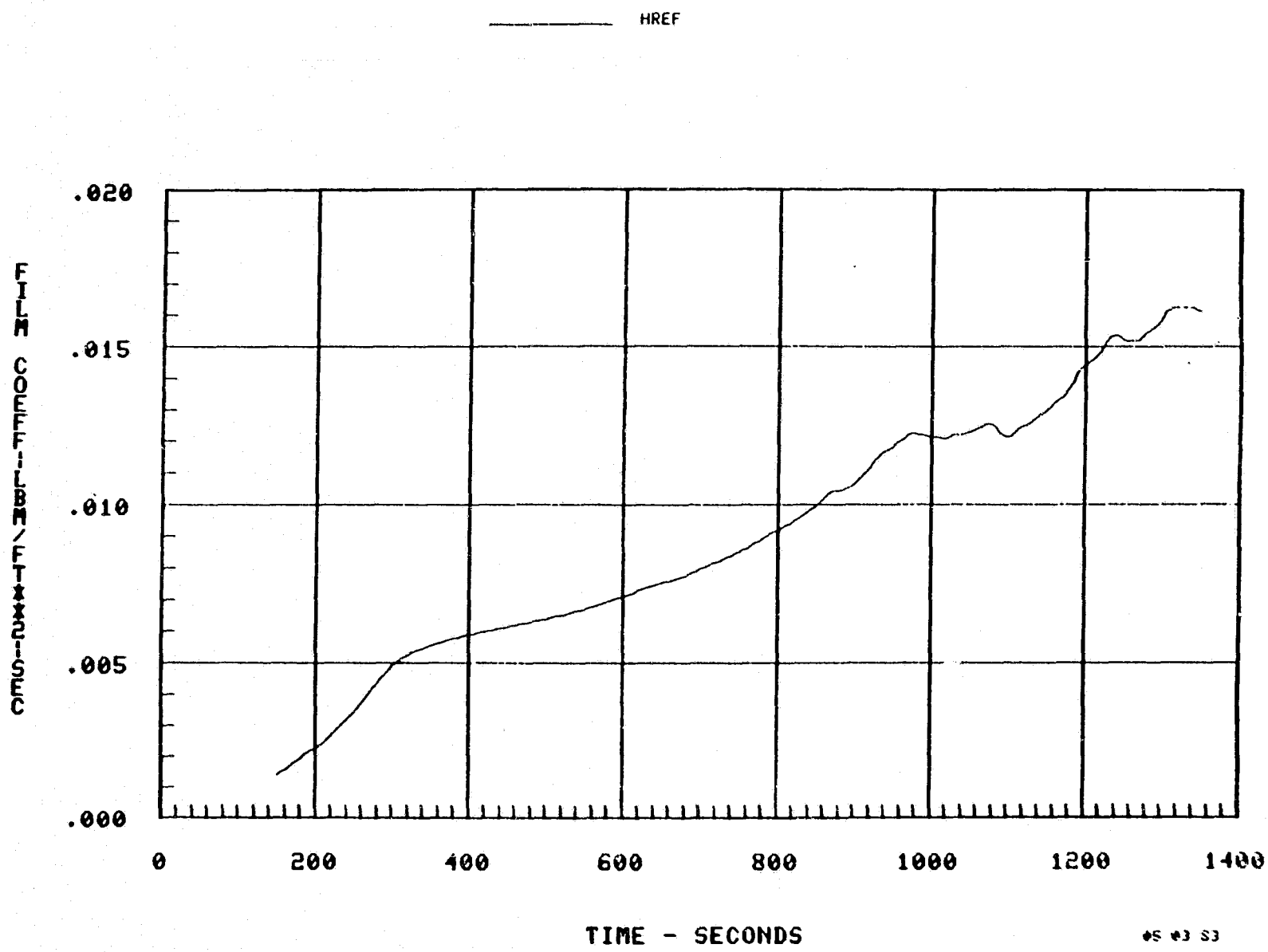

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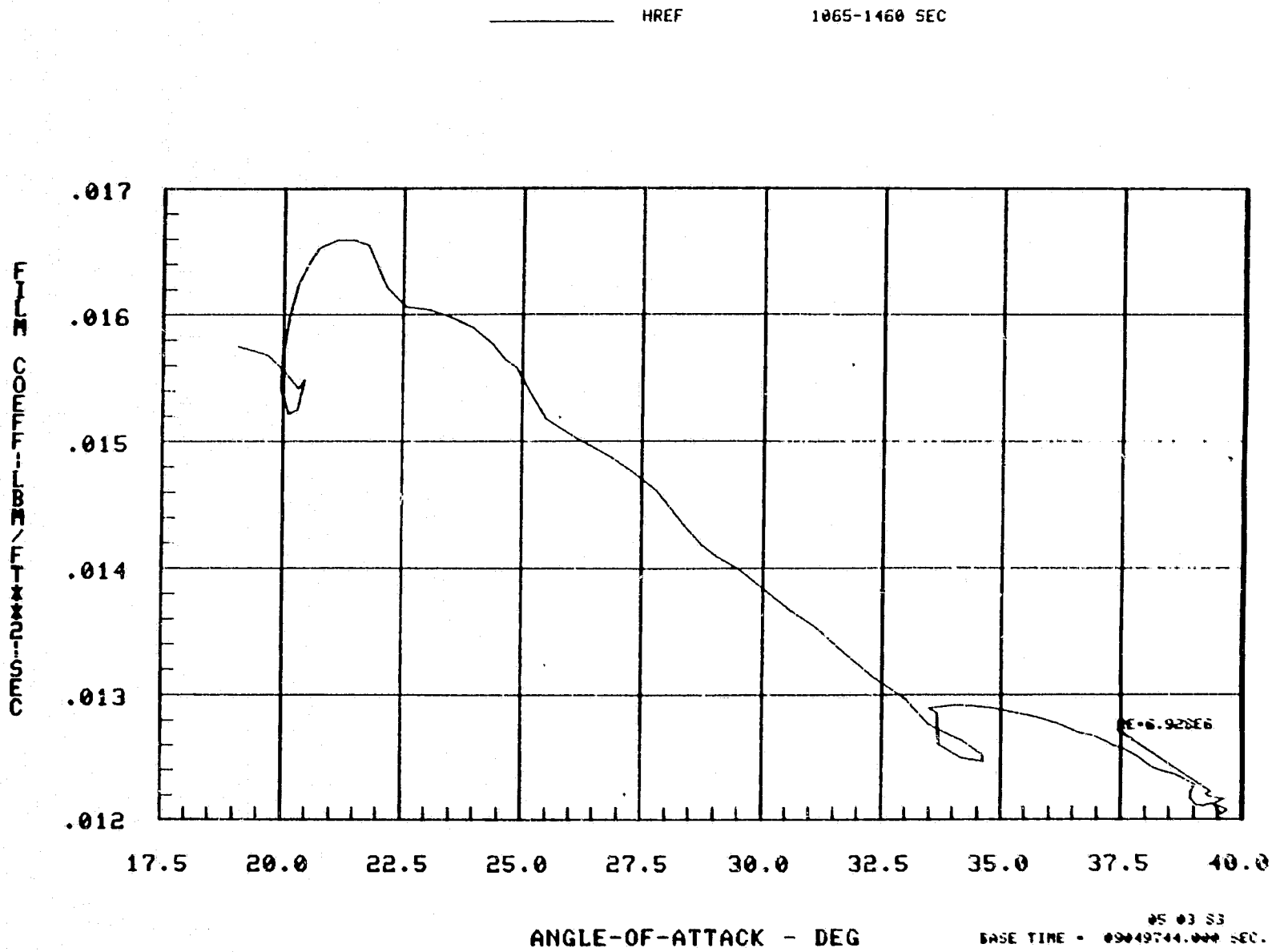

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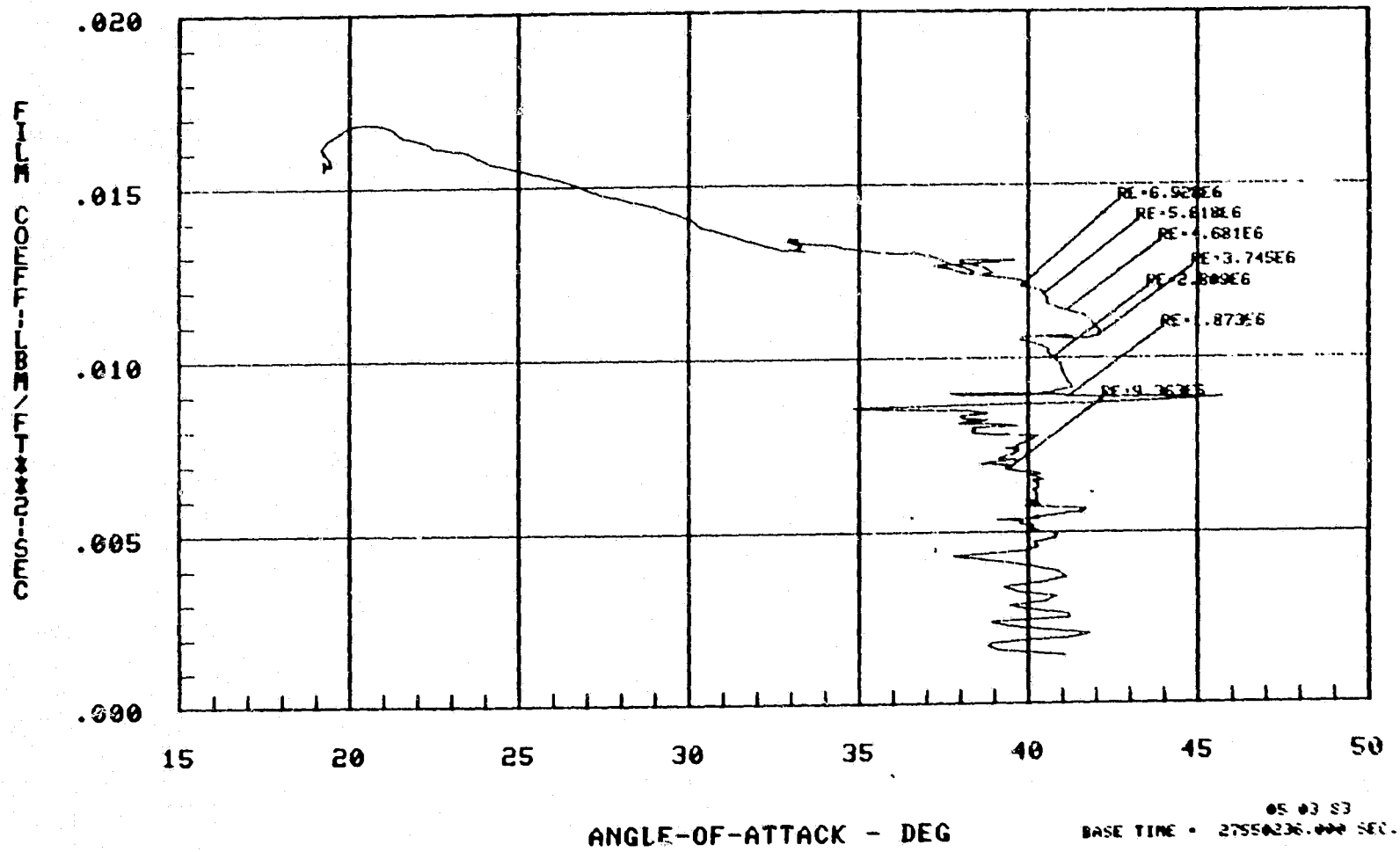

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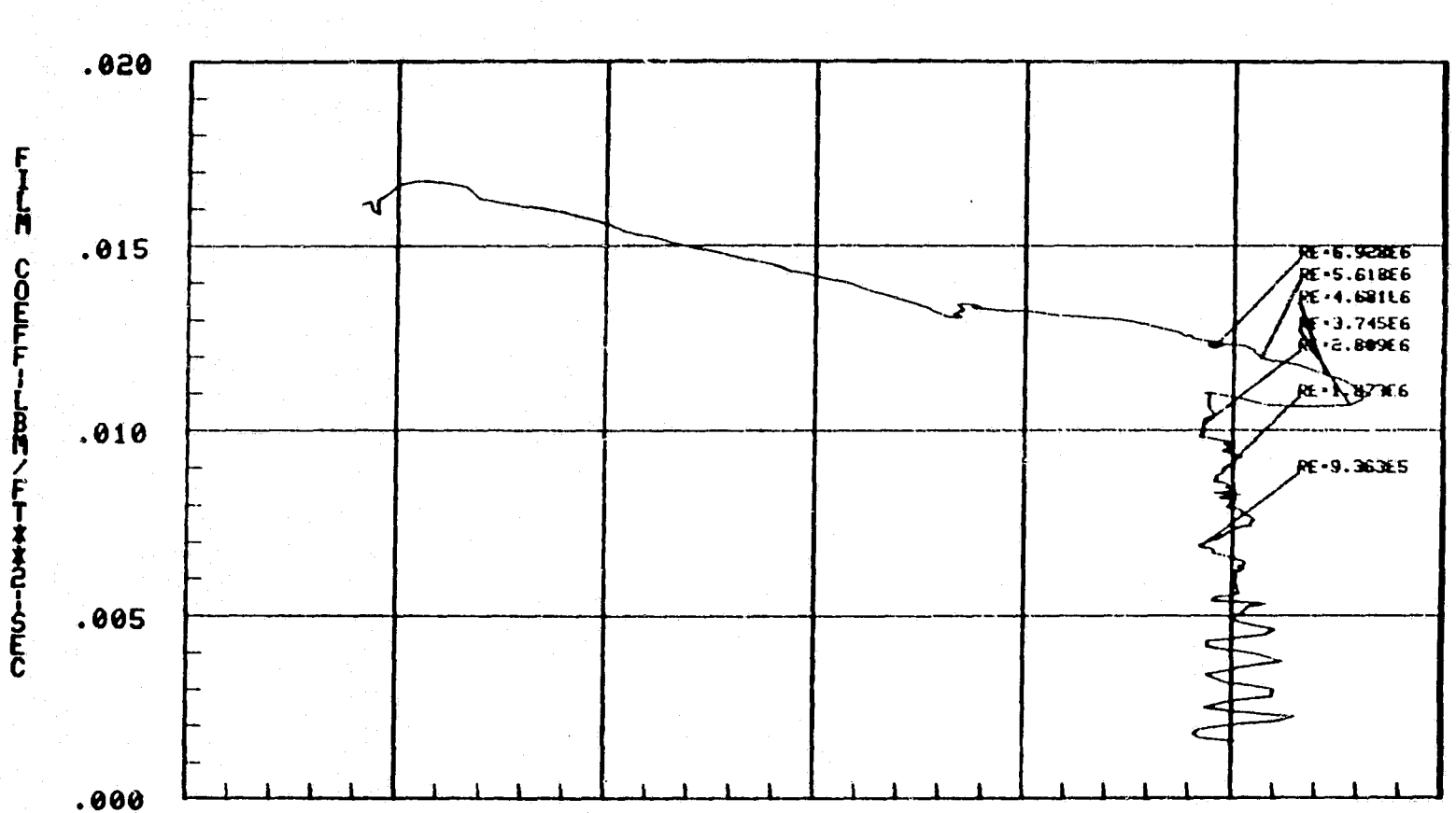

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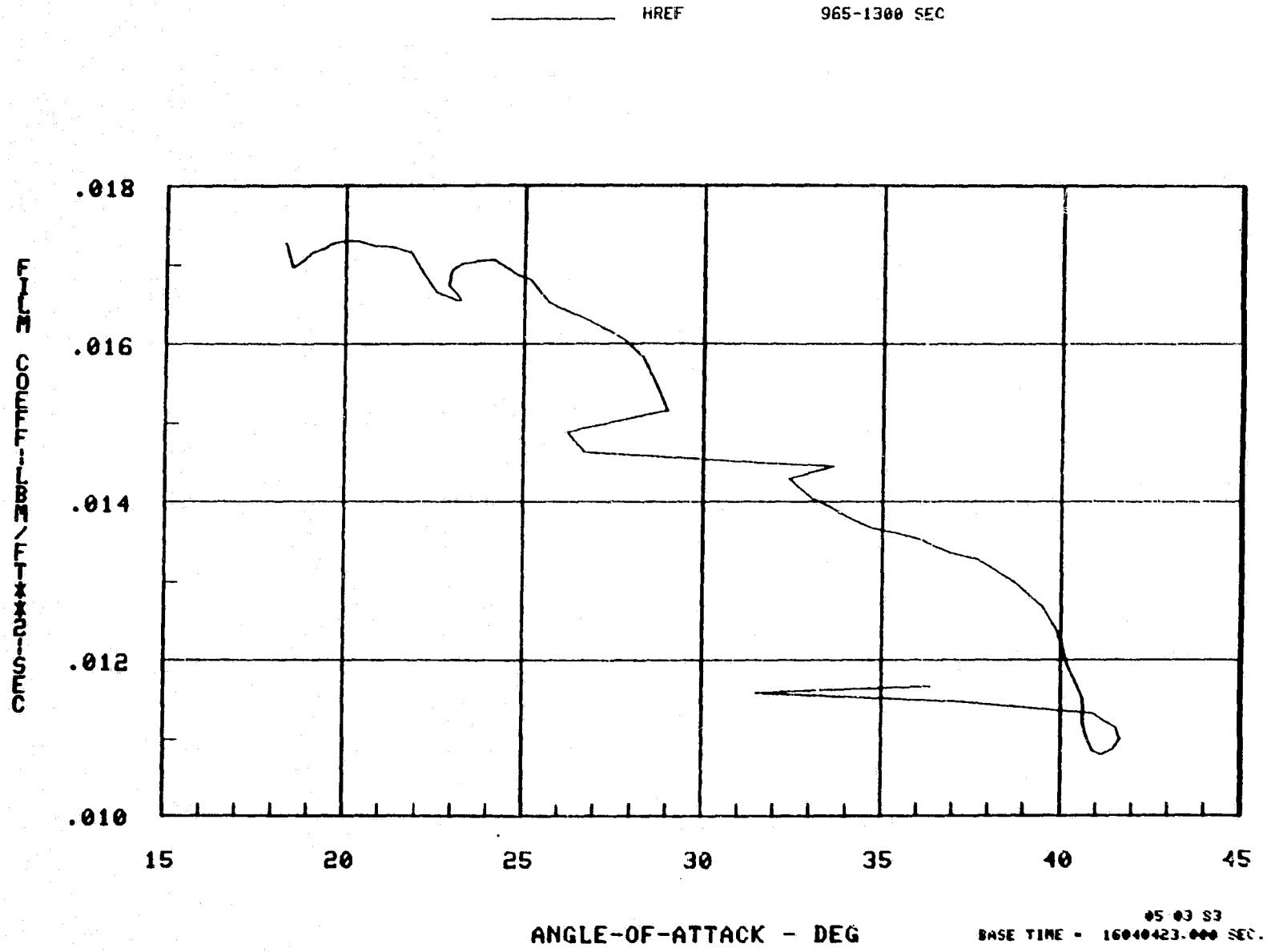

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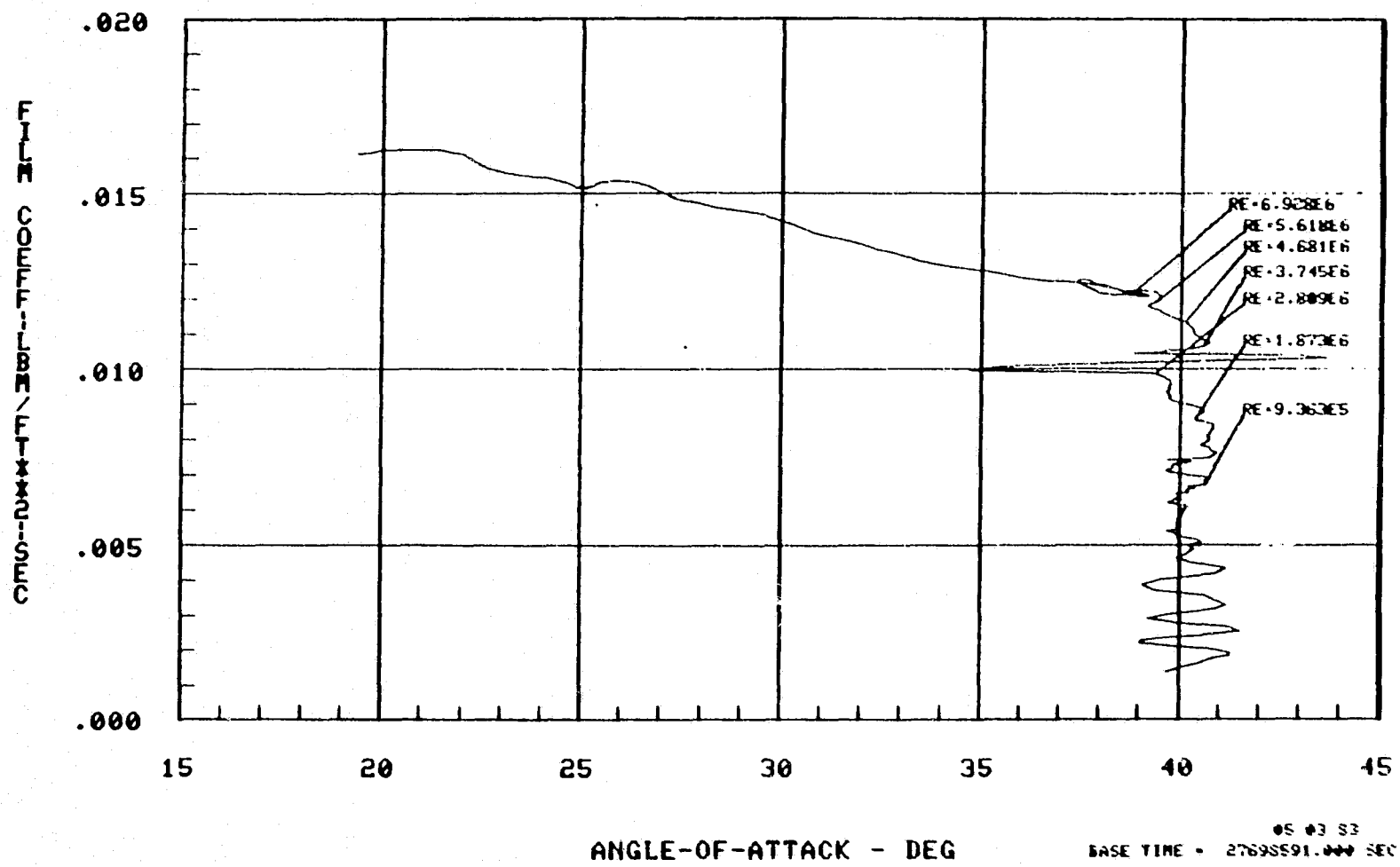

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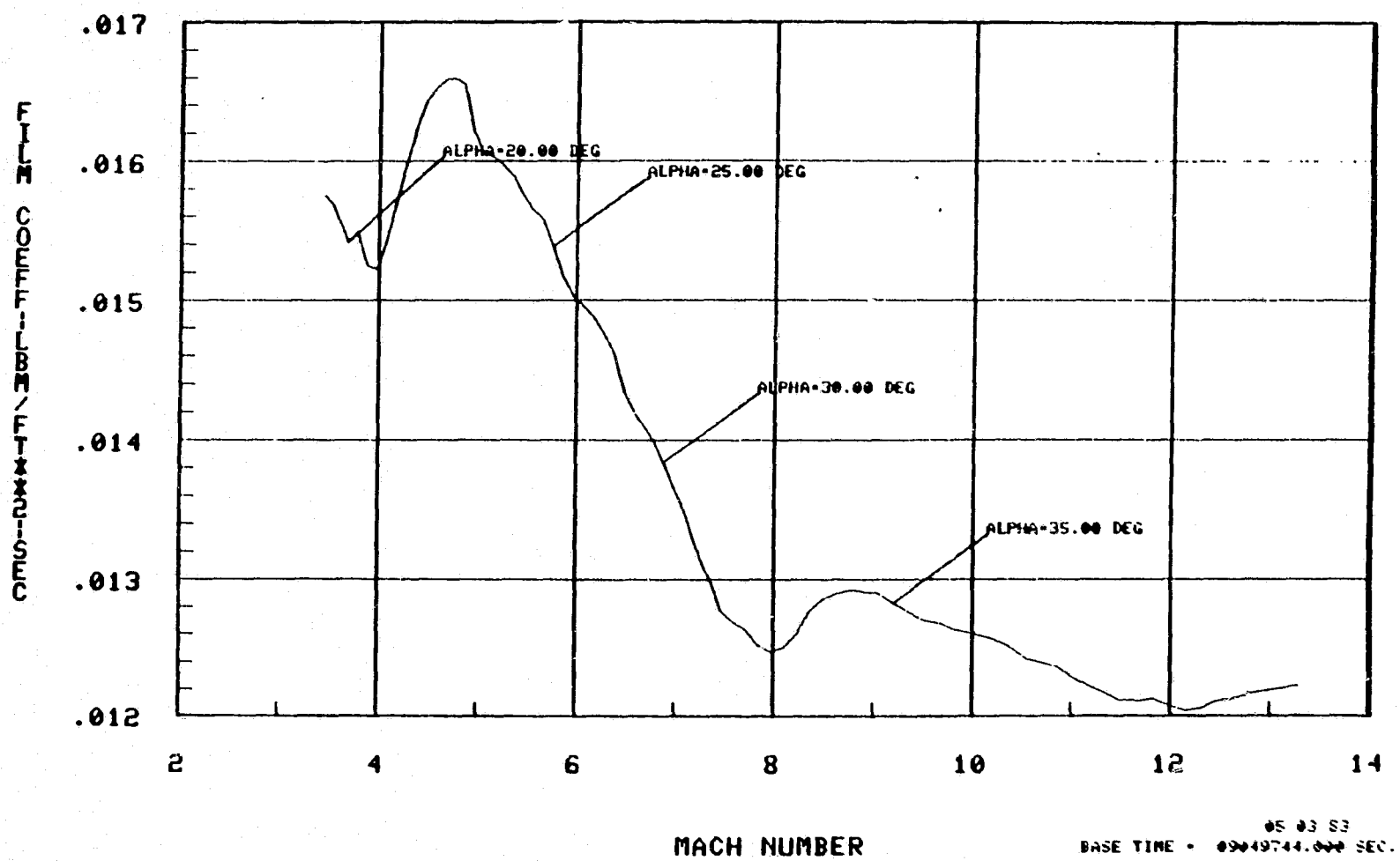

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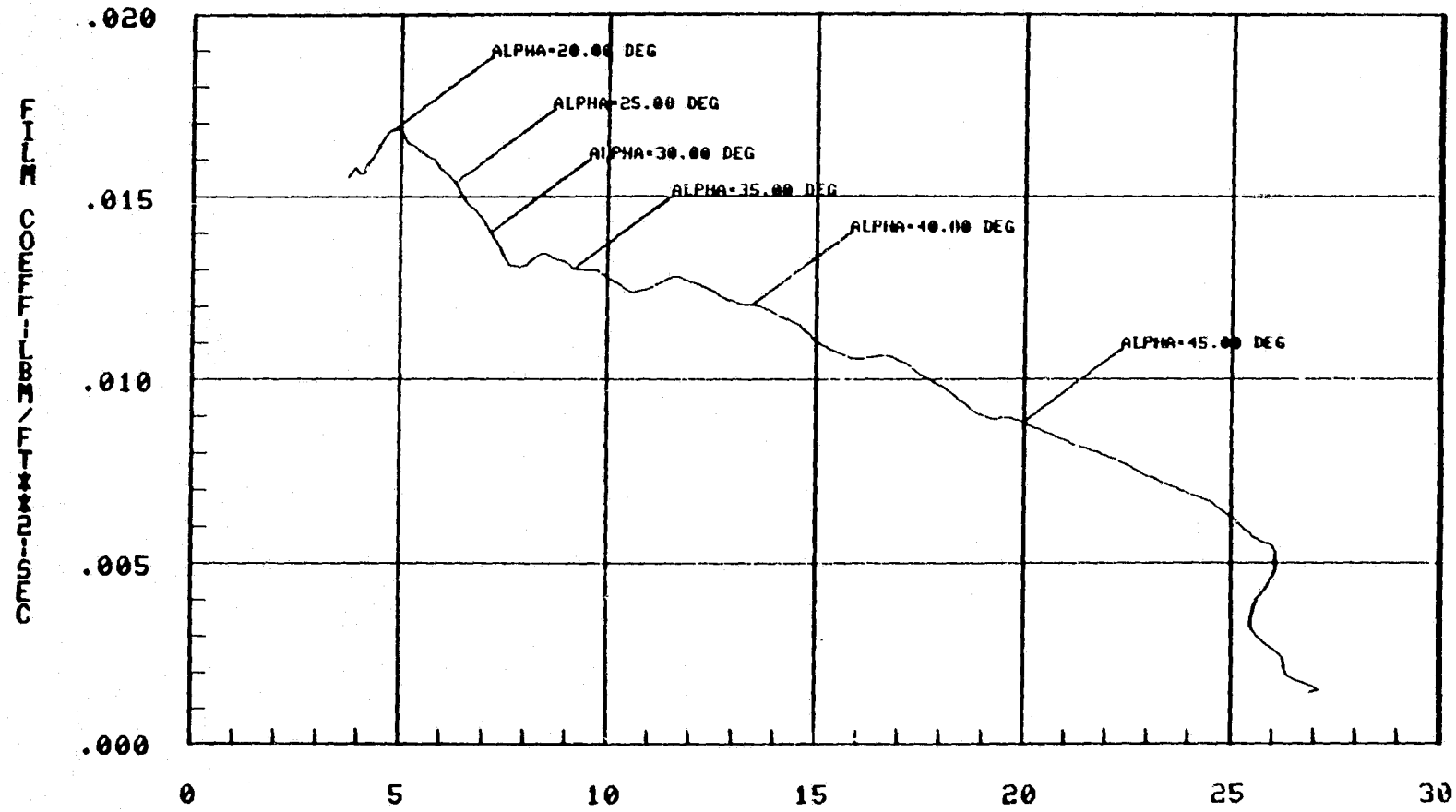

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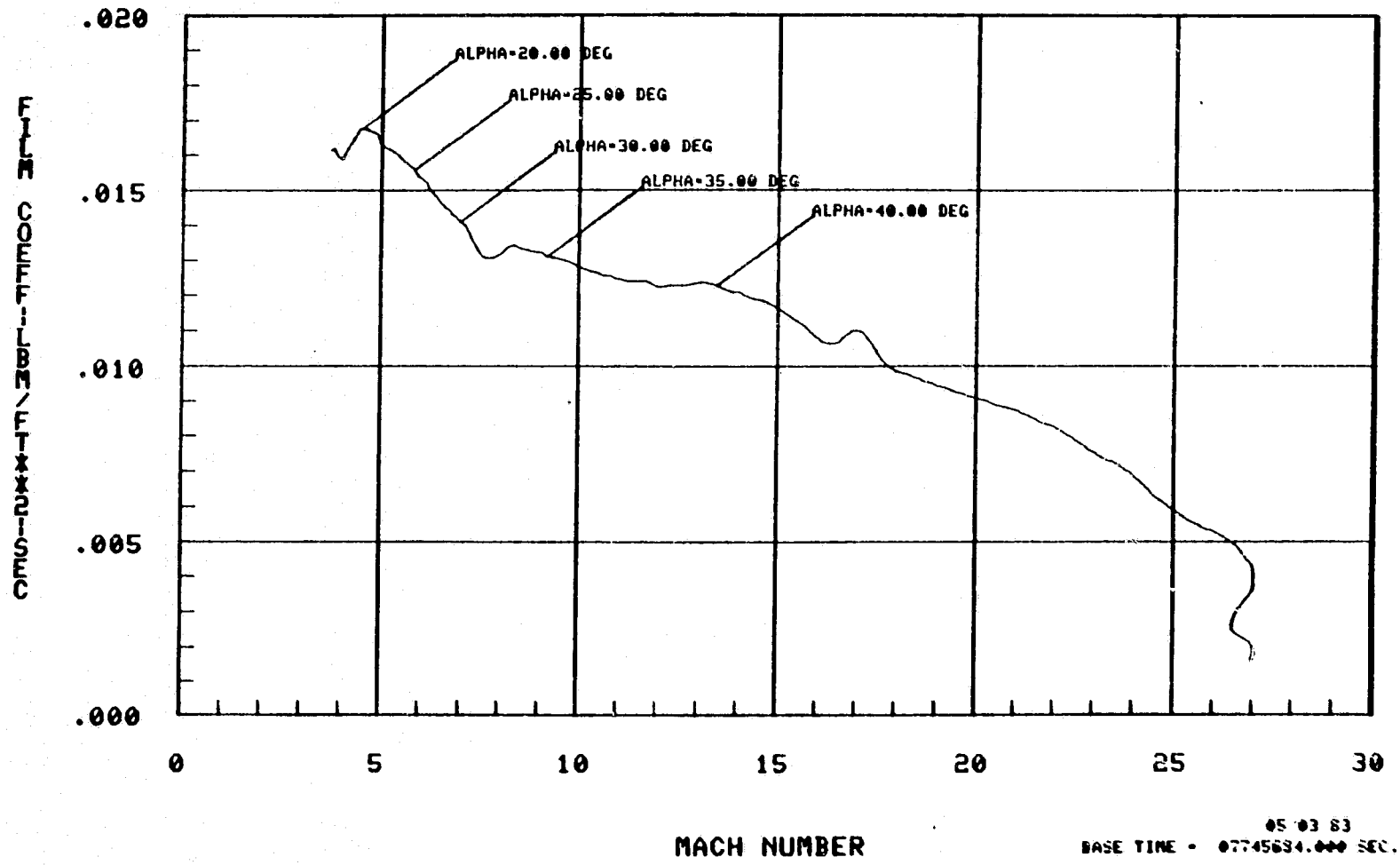

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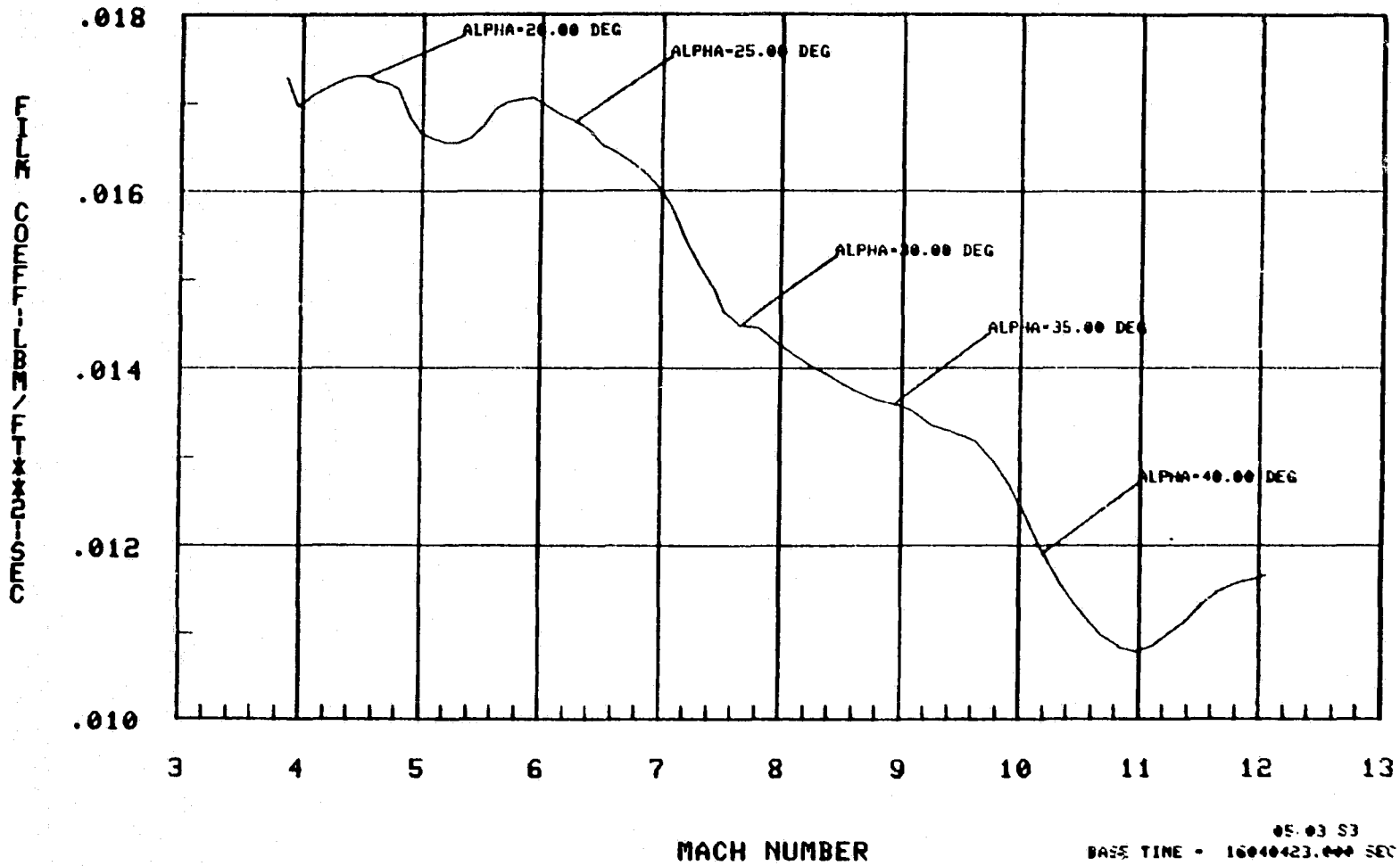

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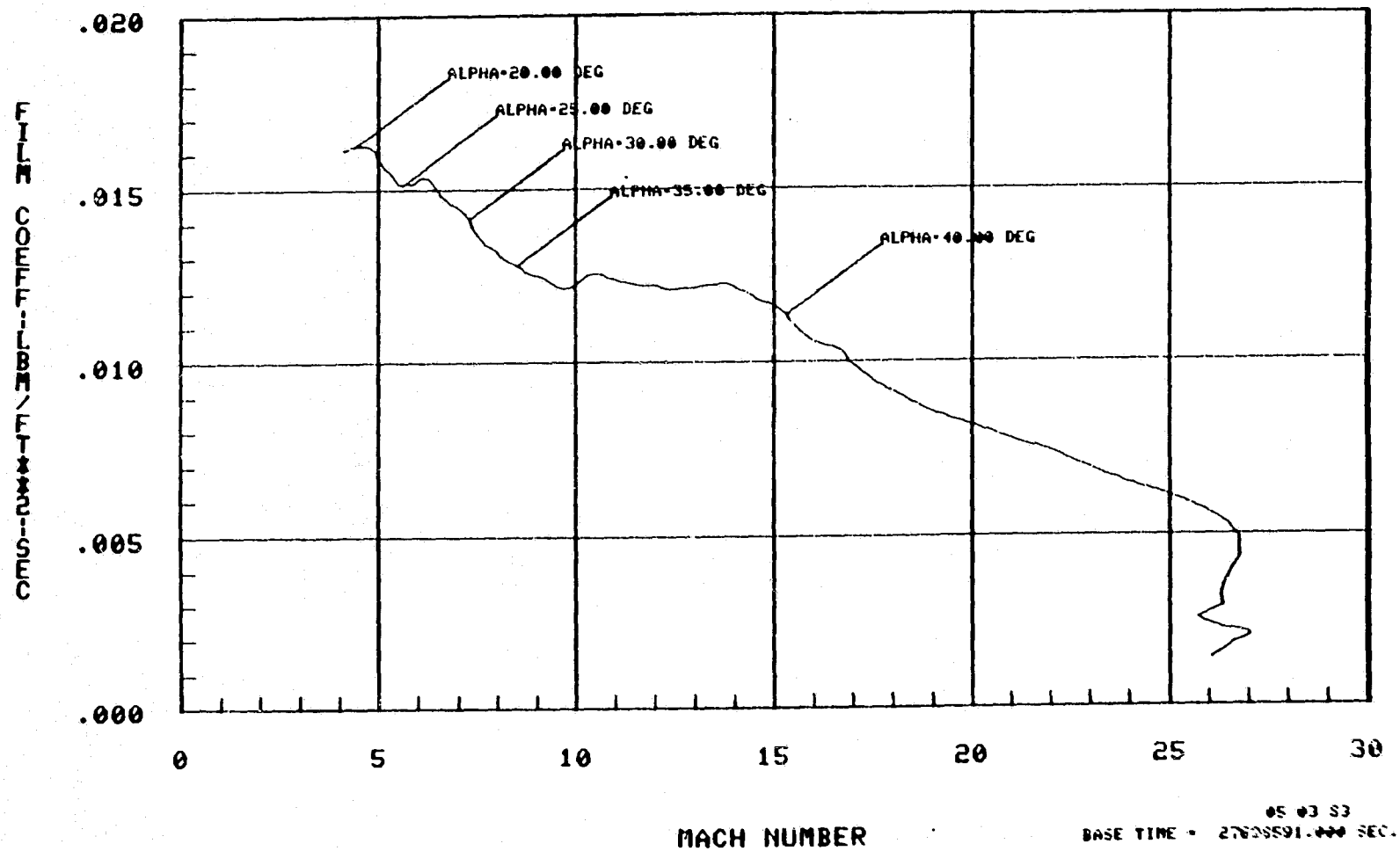

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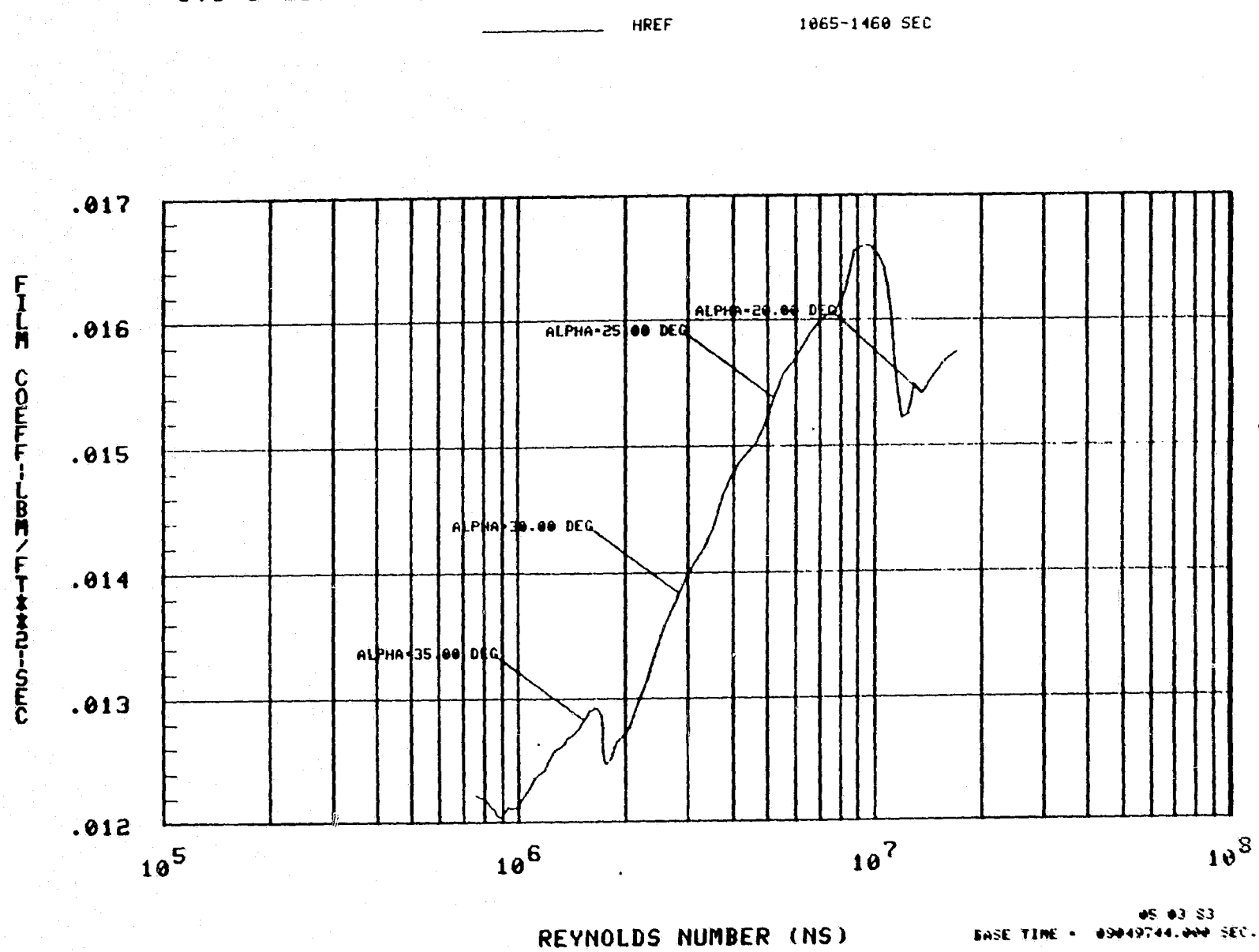

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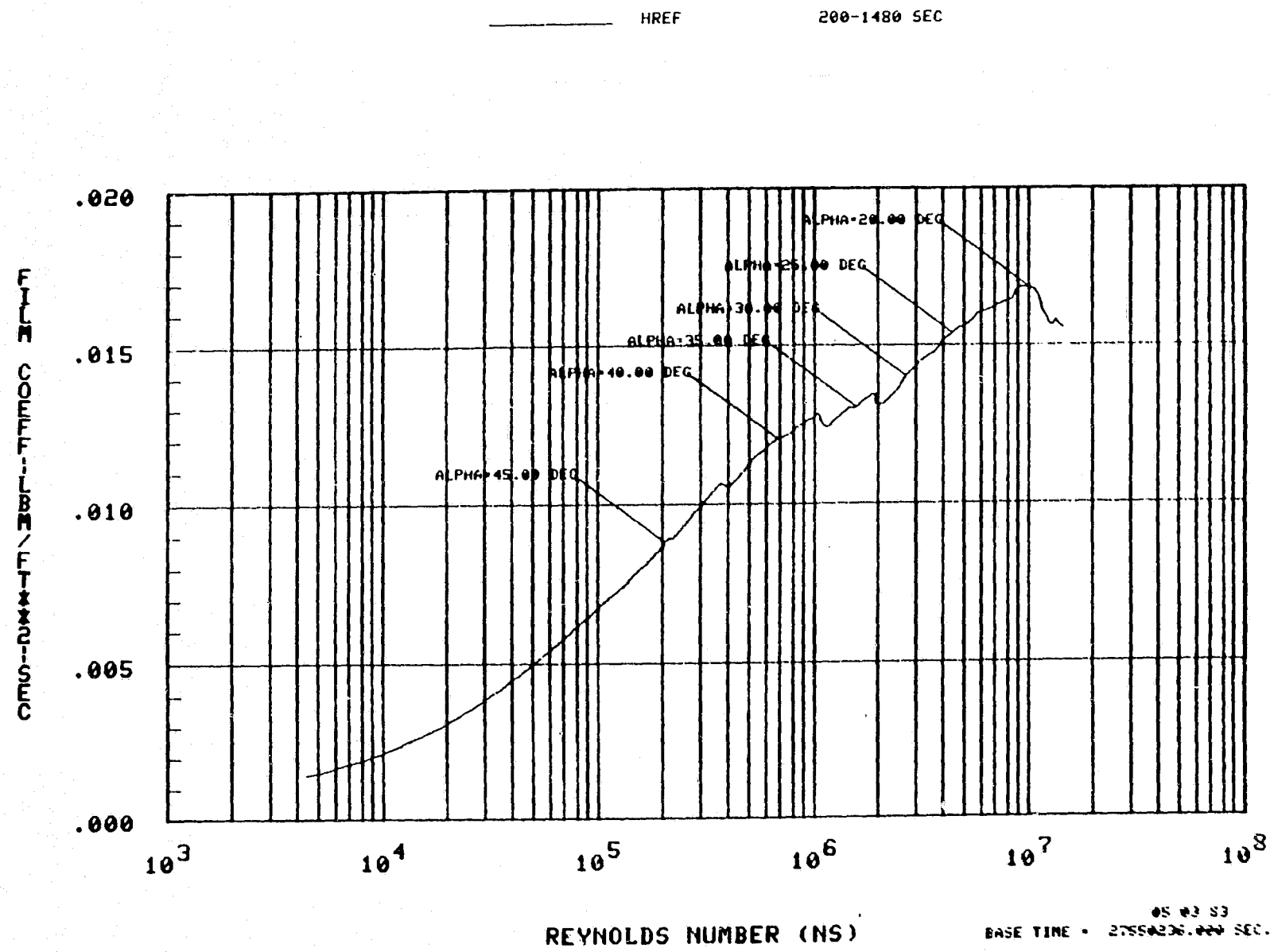

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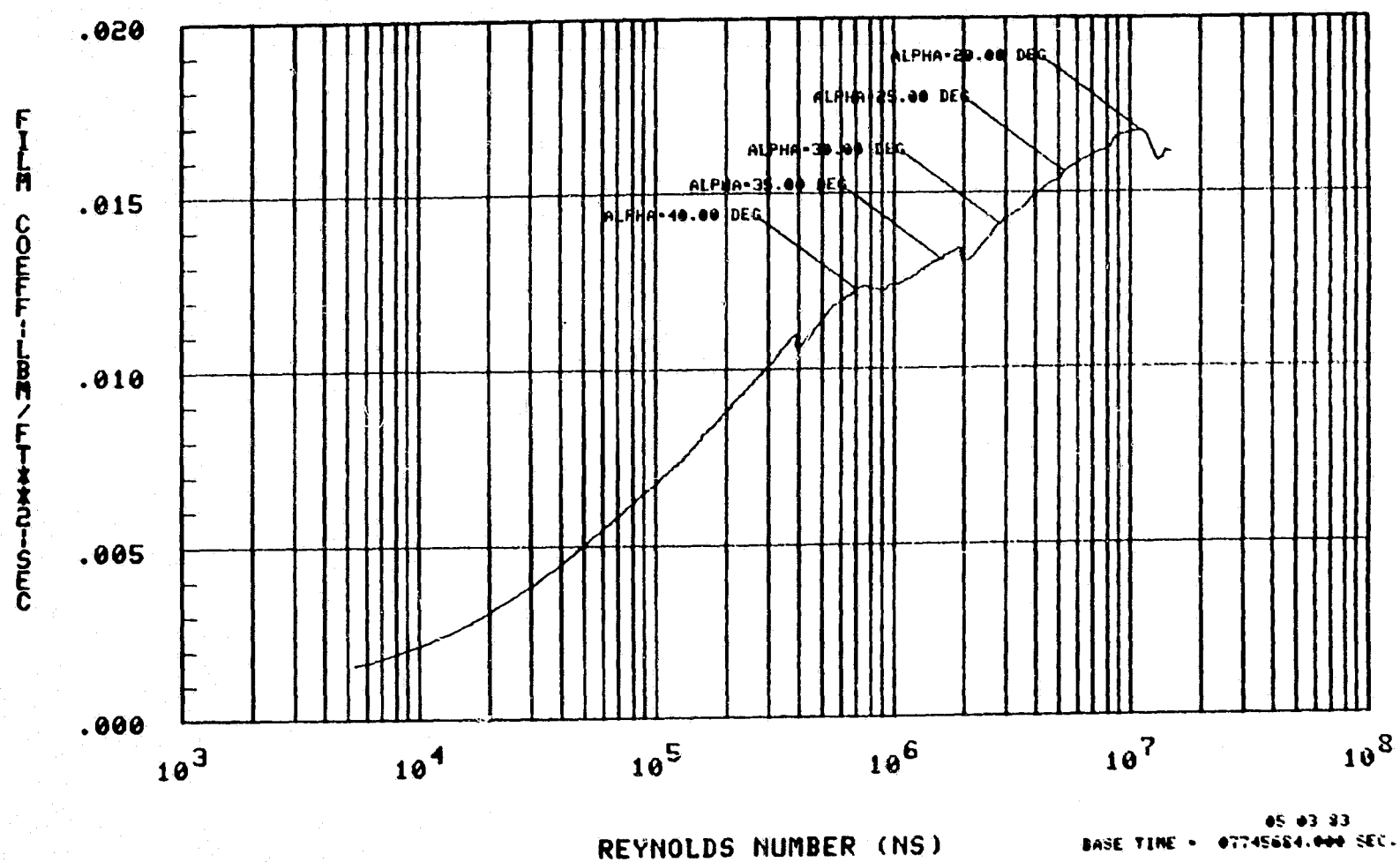

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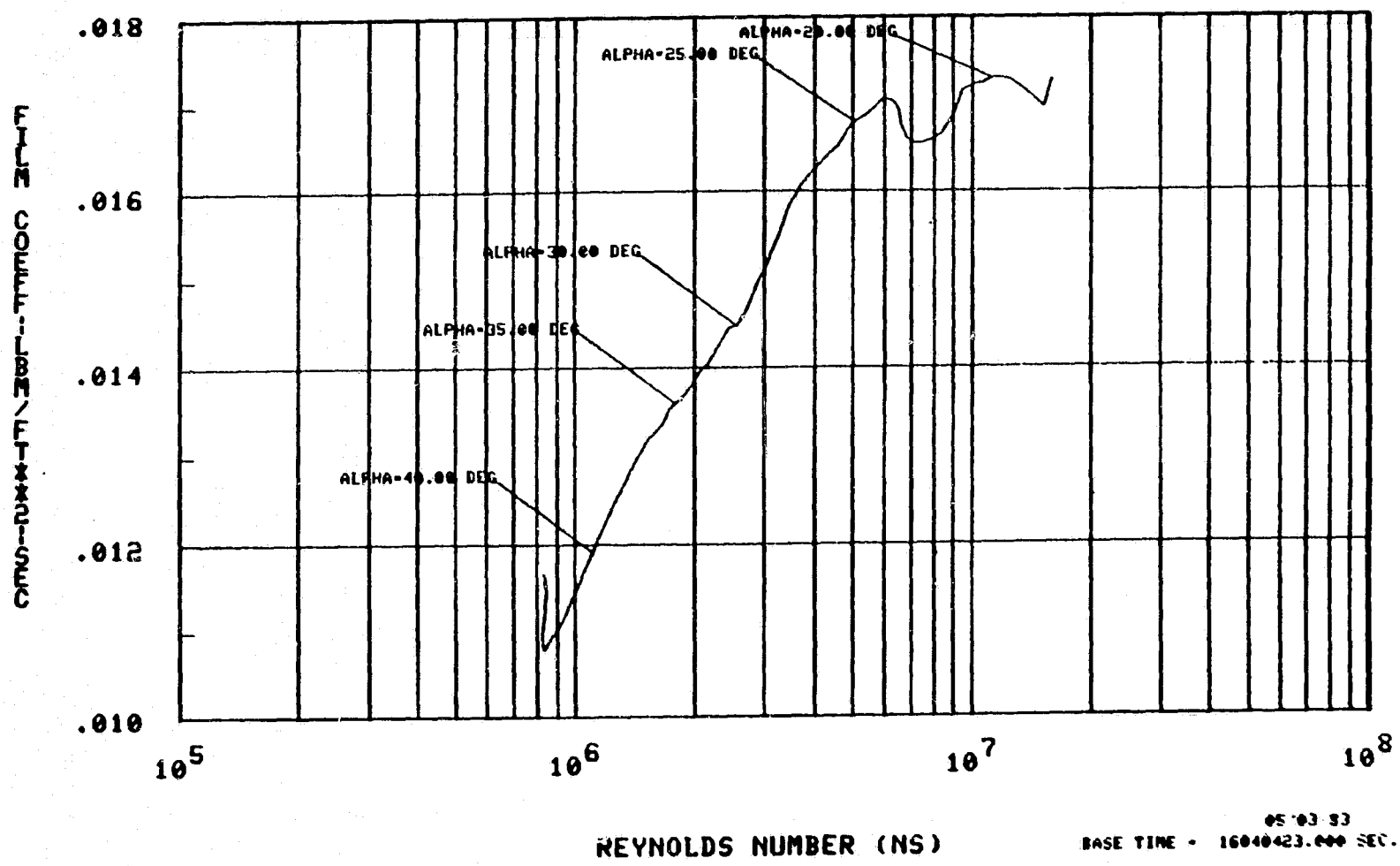

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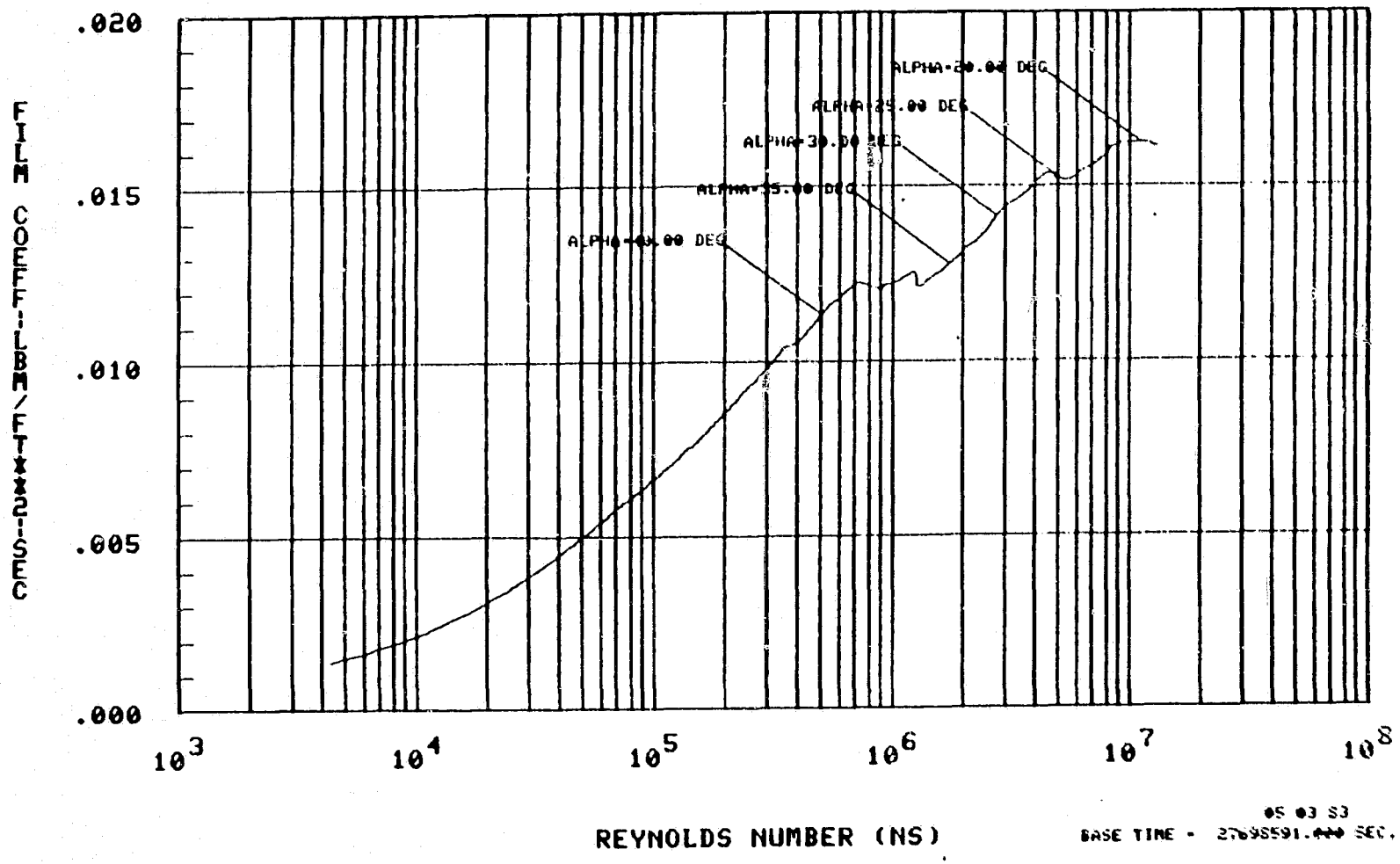

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APPENDIX B

FLIGHT DATA

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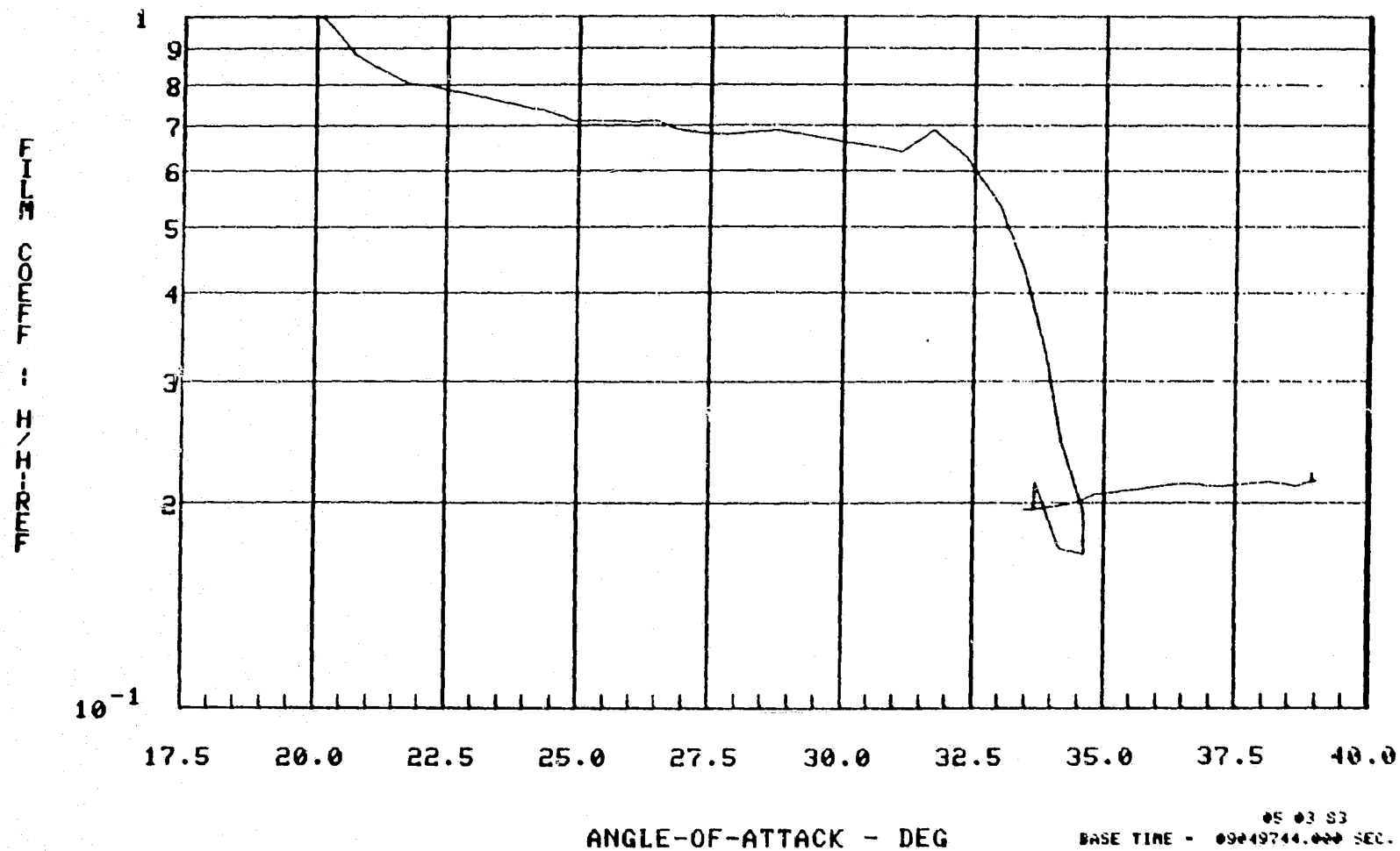

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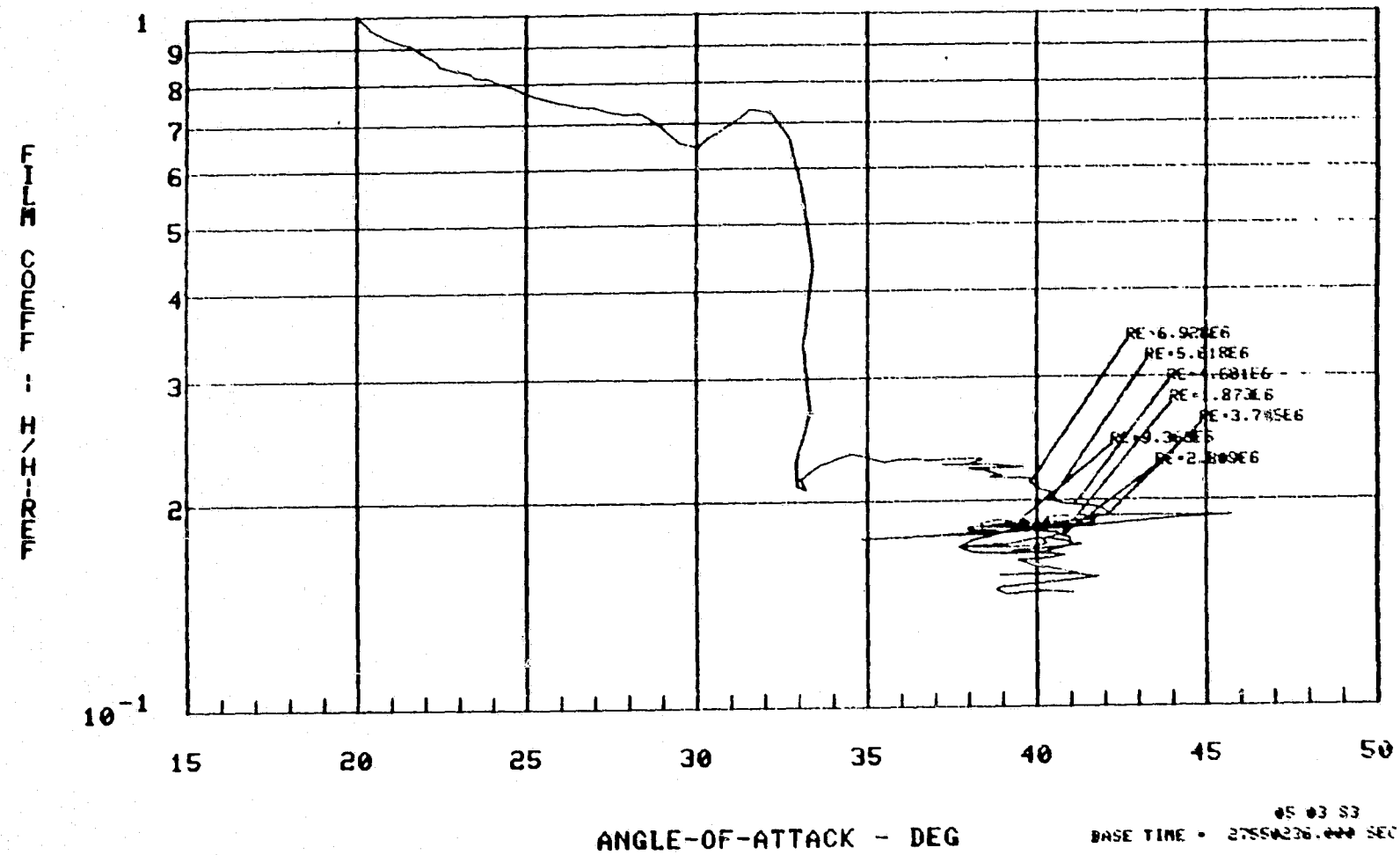

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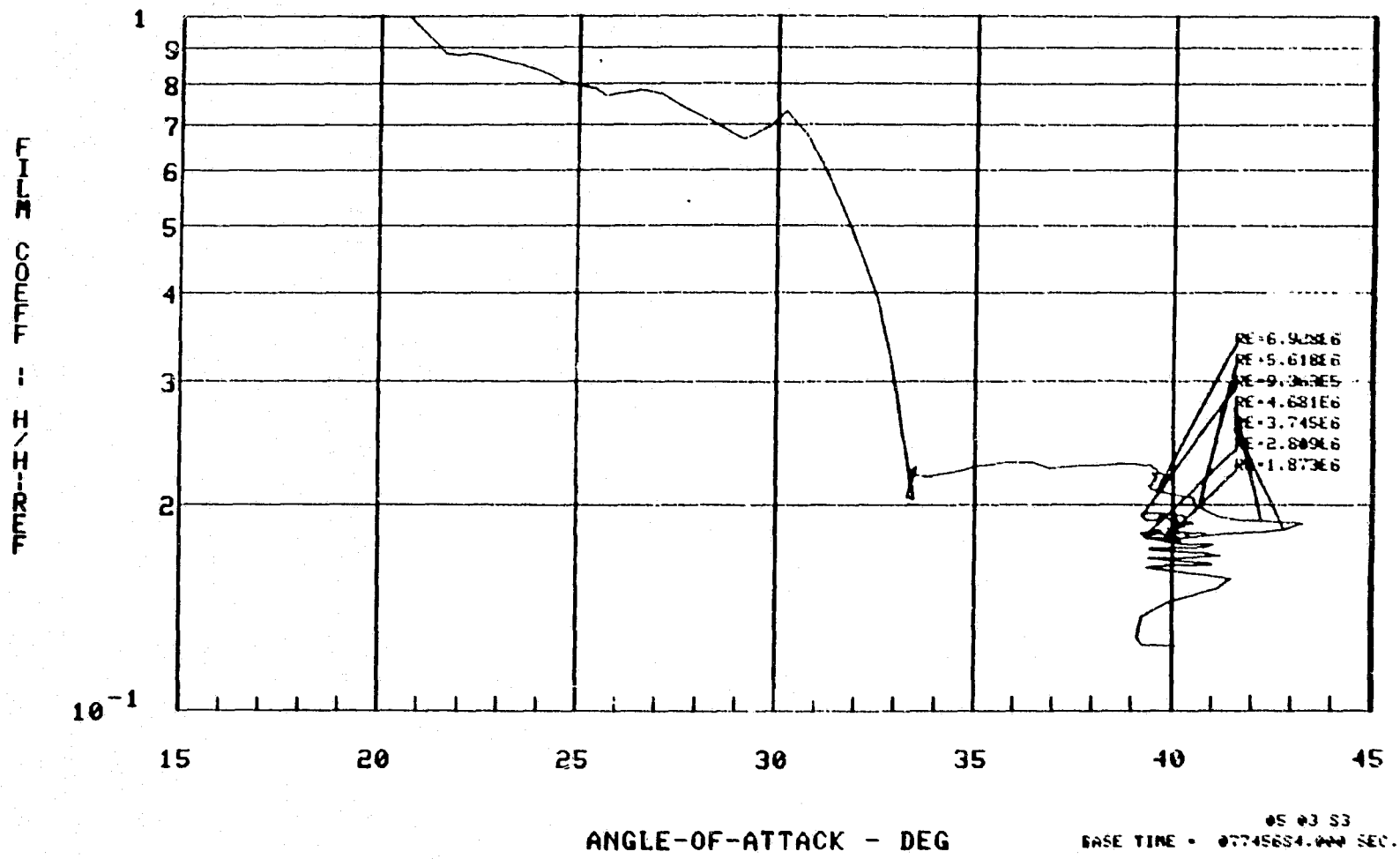

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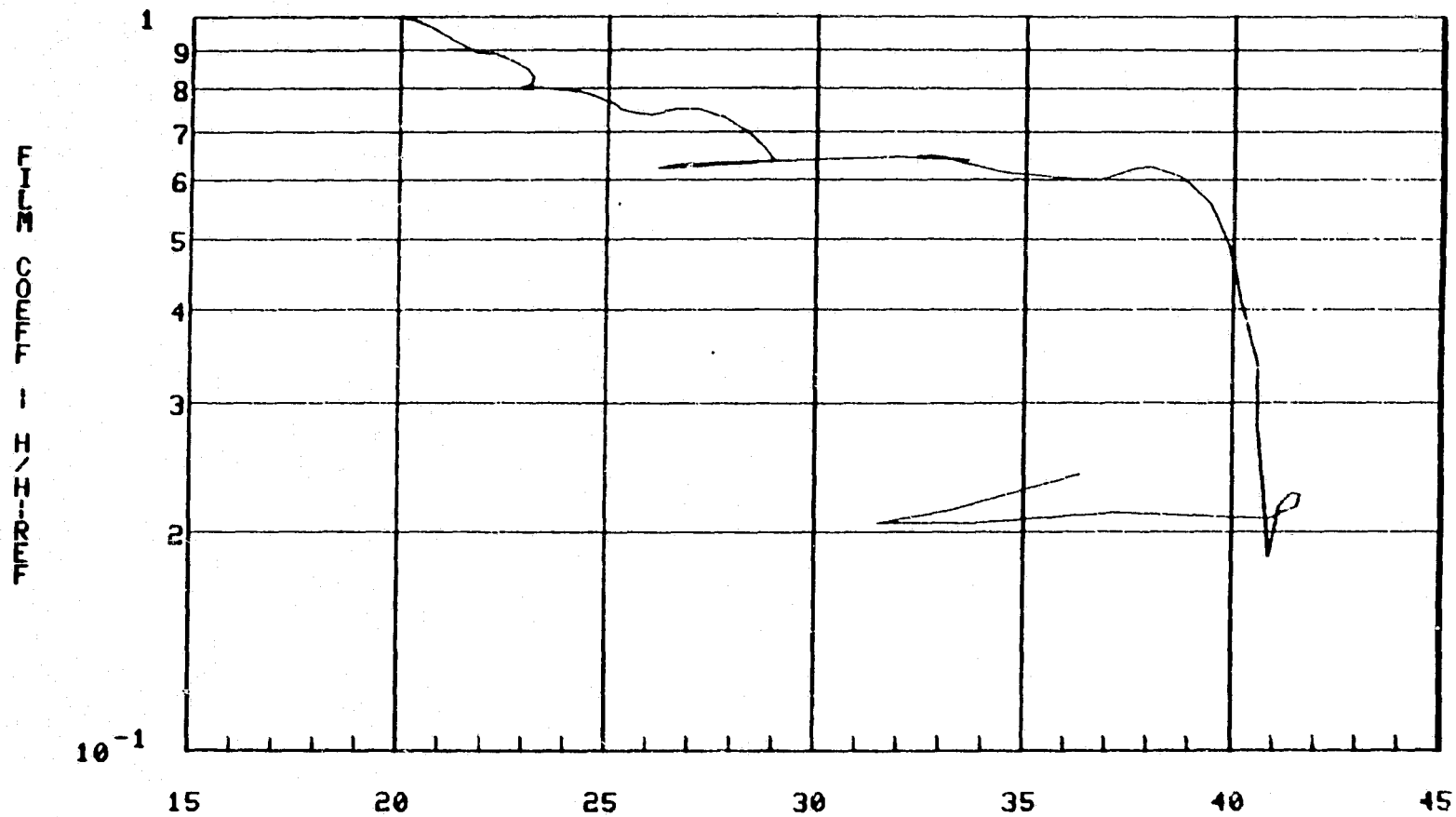

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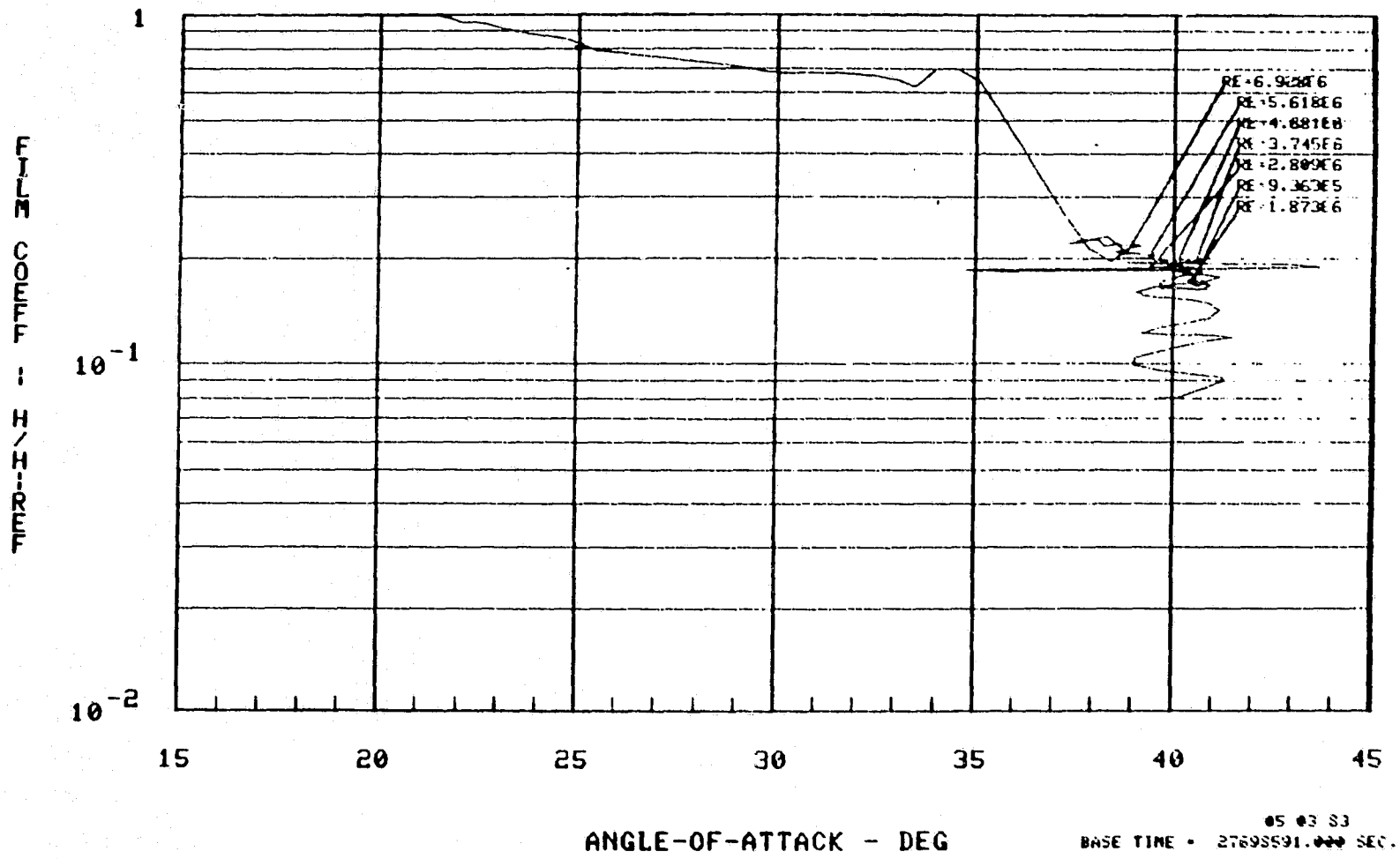

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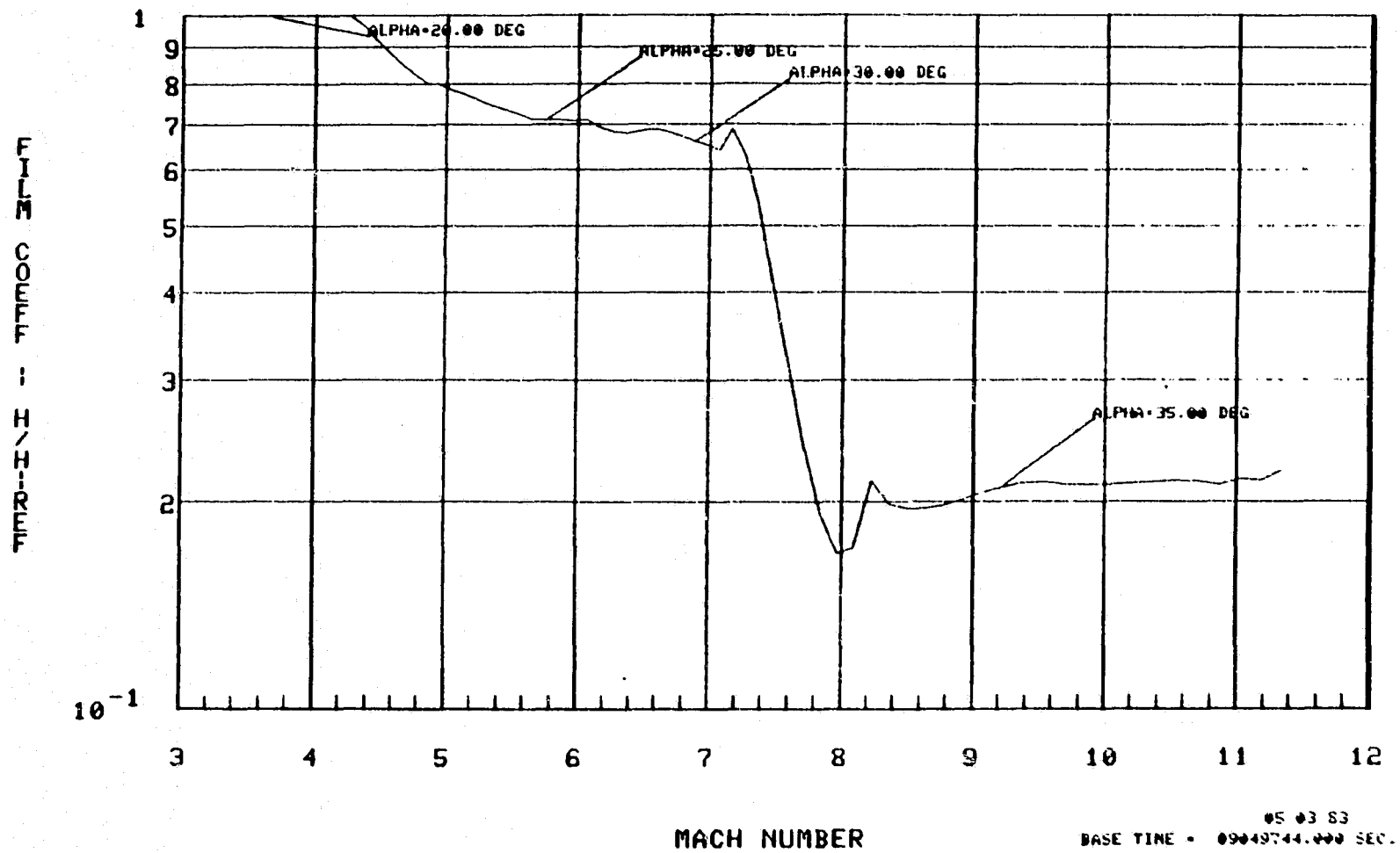

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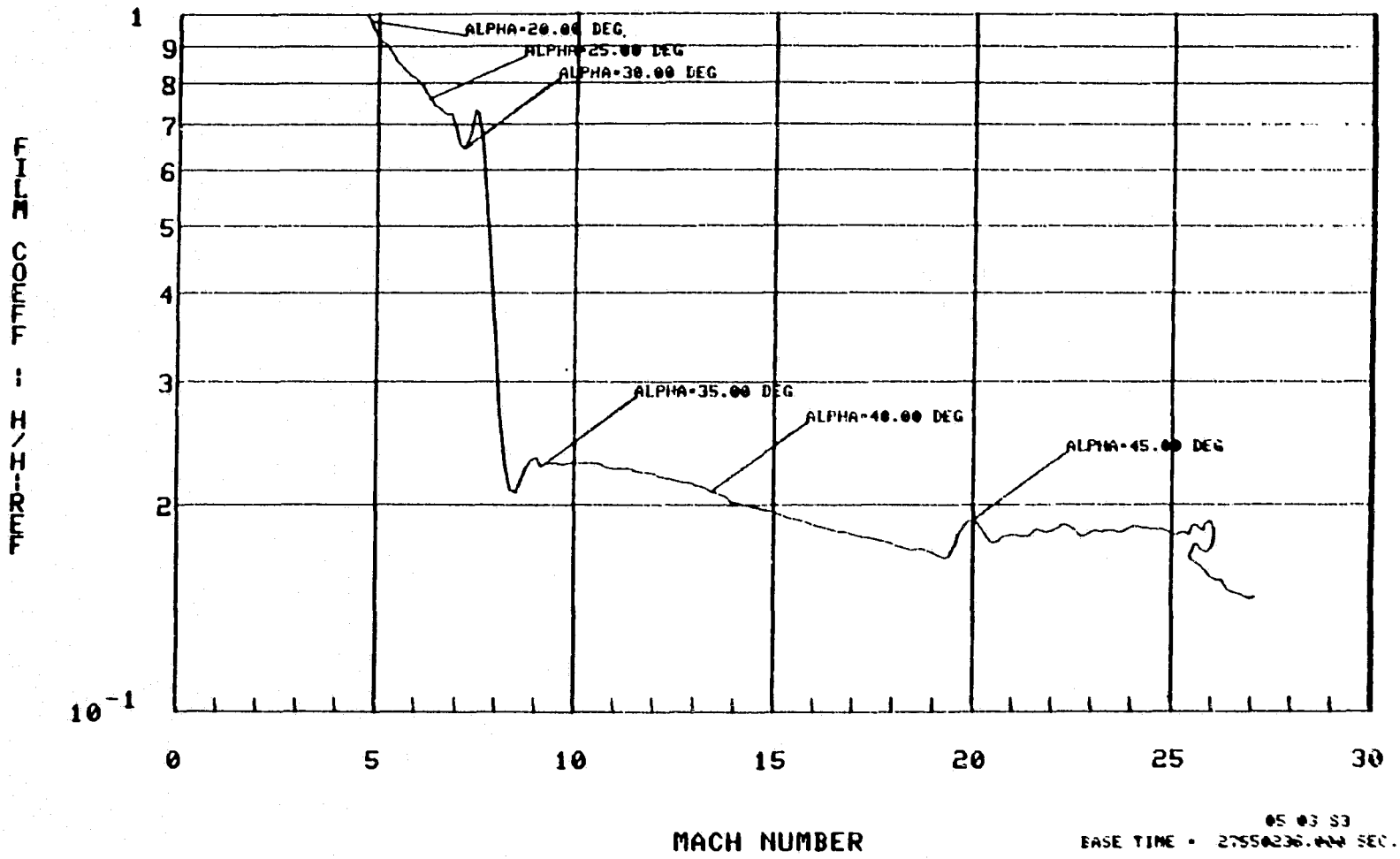

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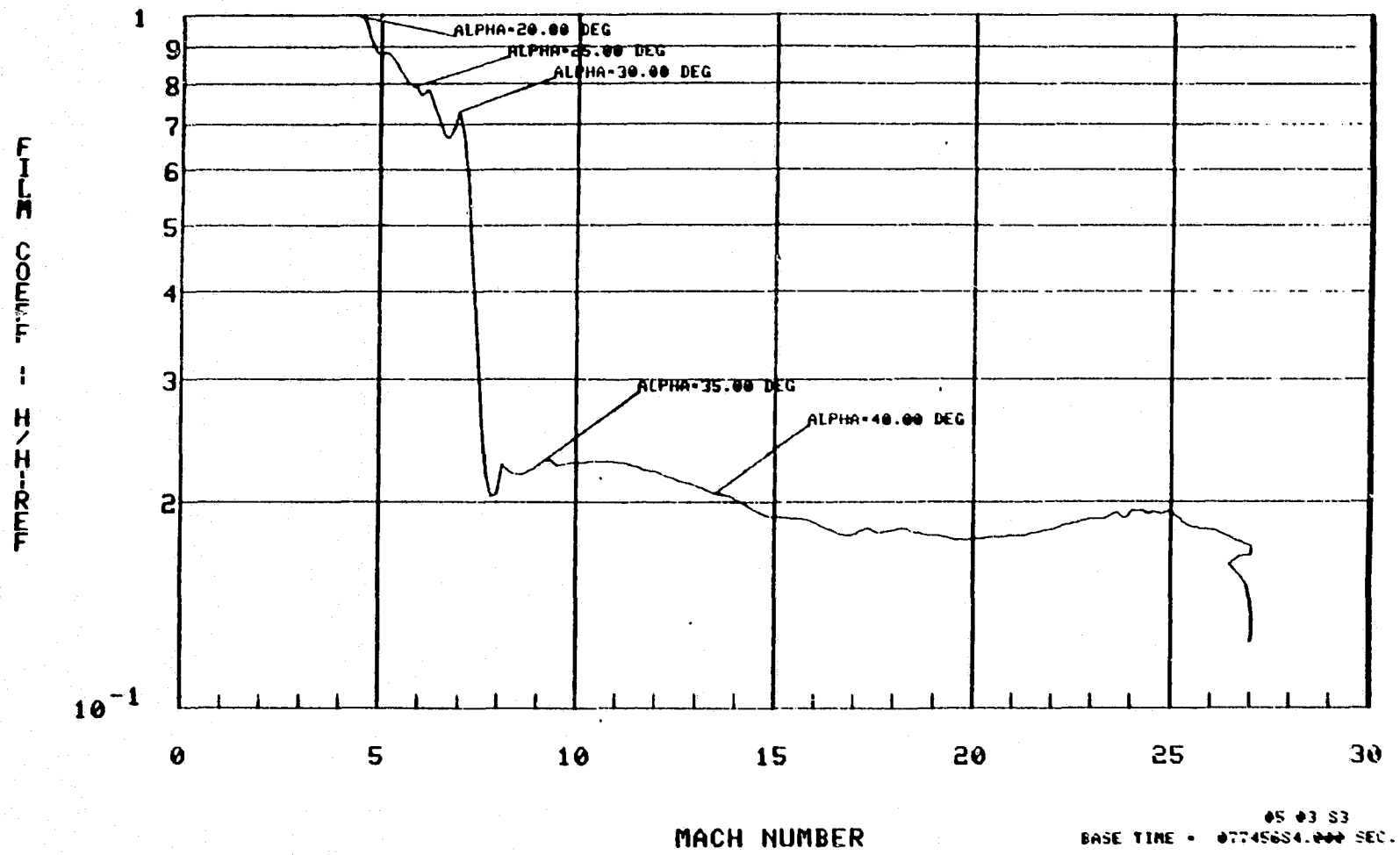

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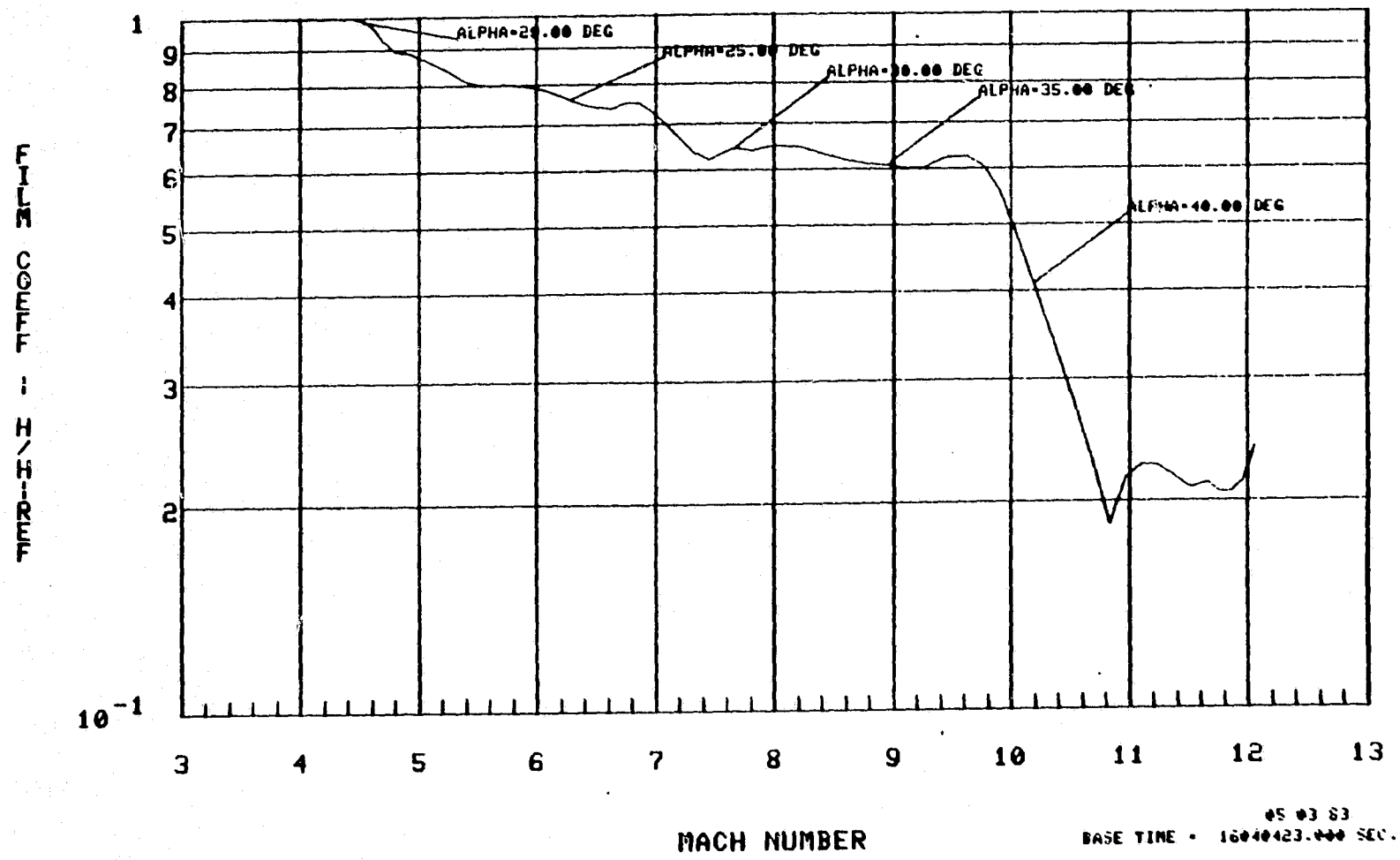

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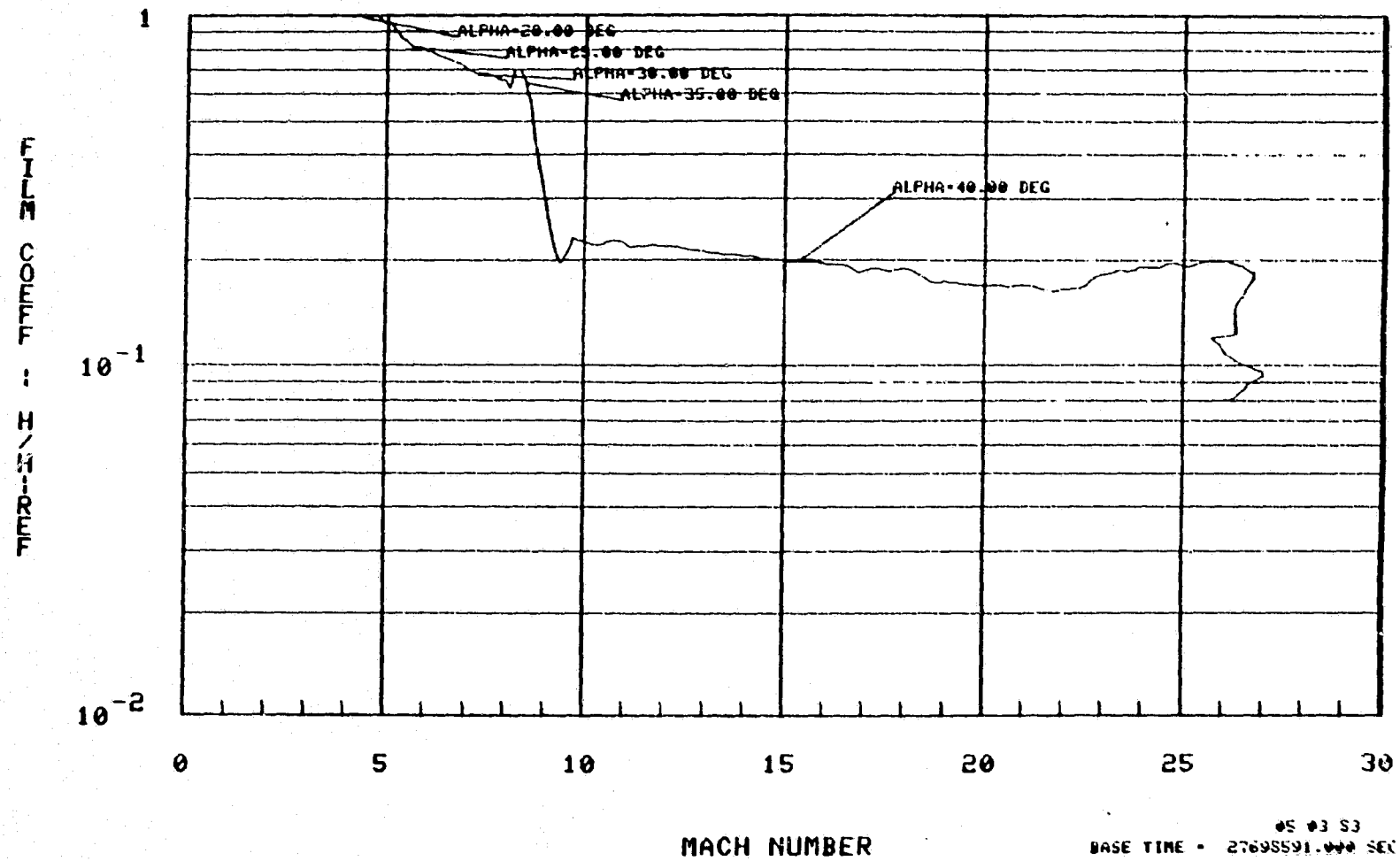

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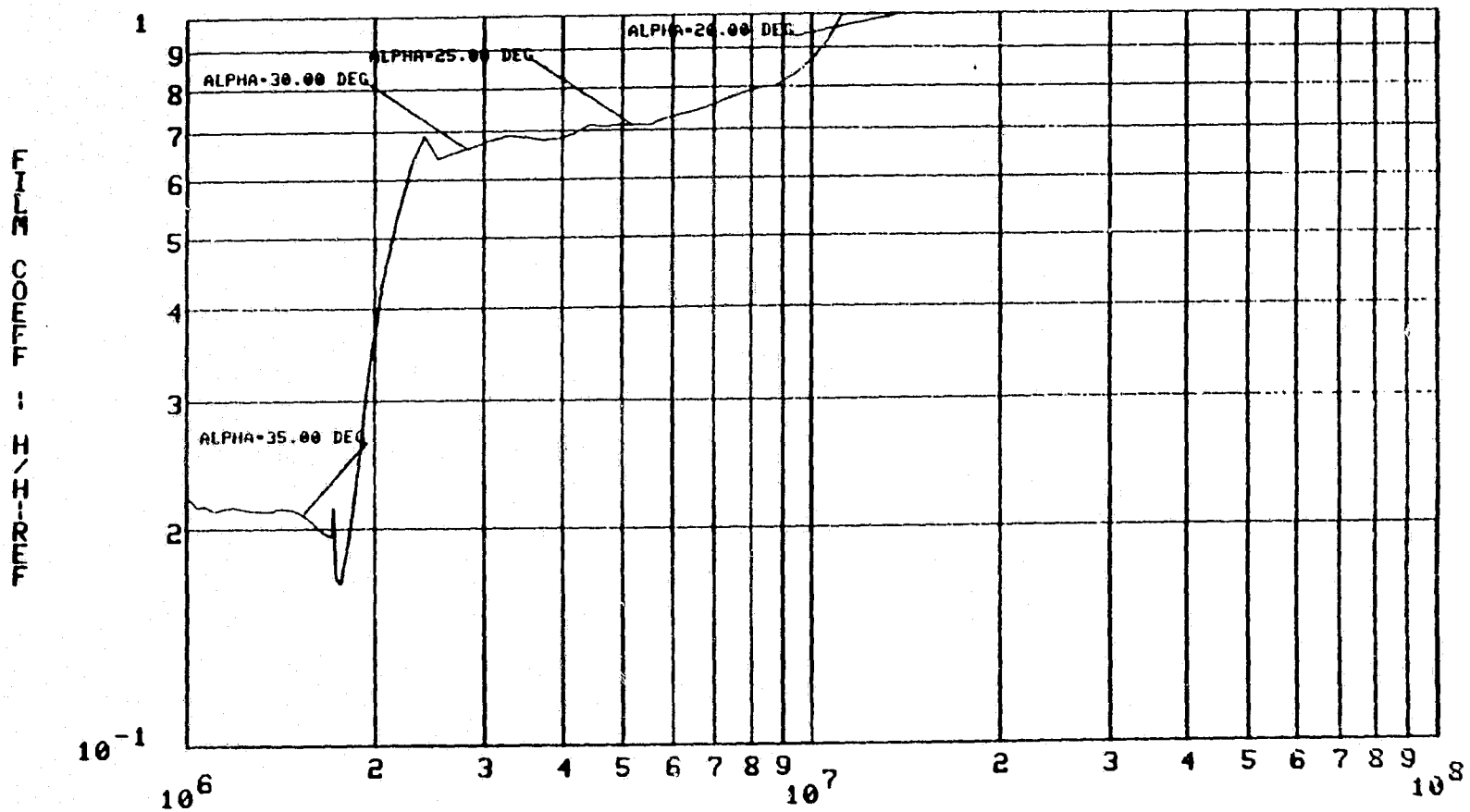

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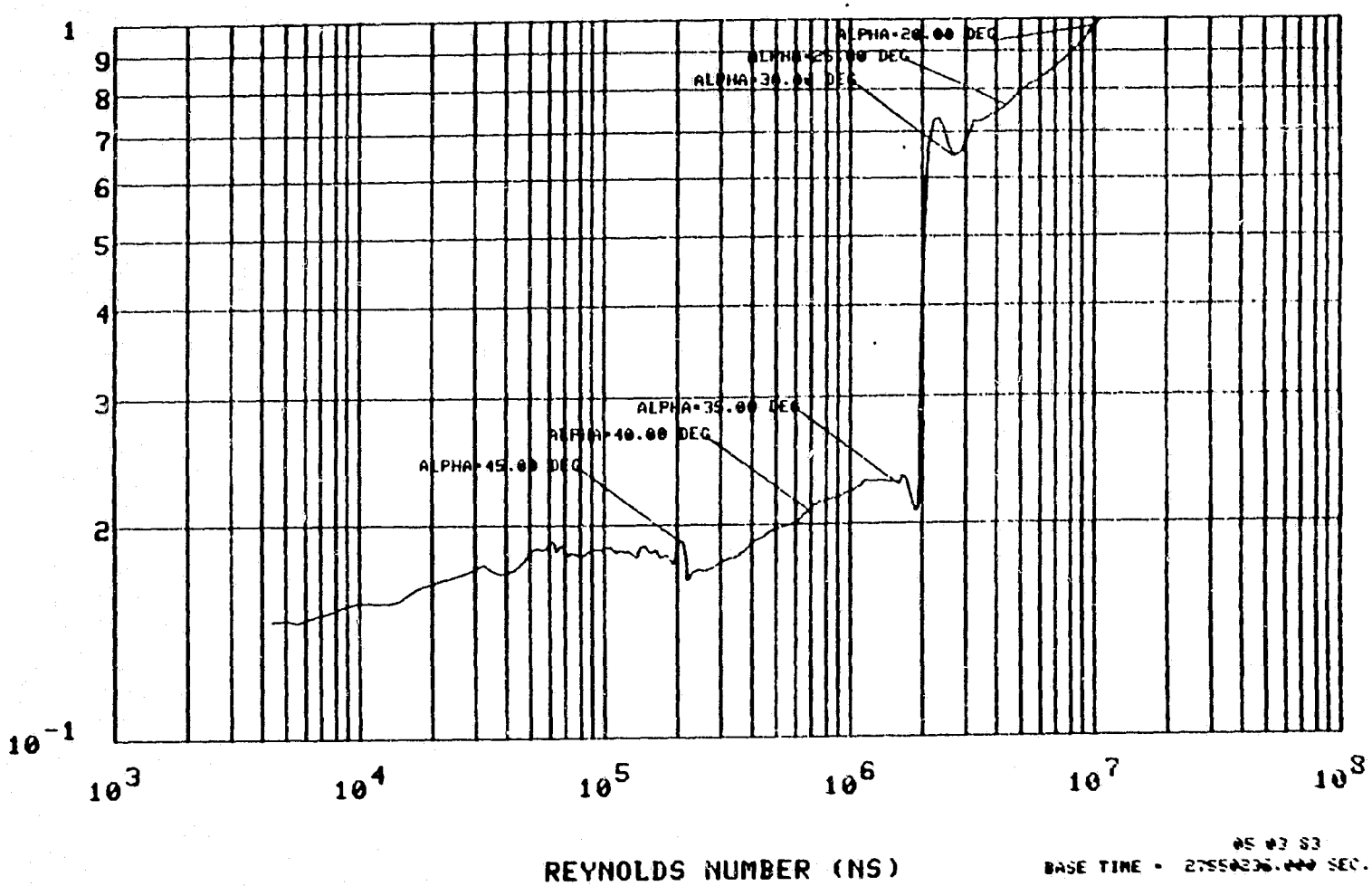

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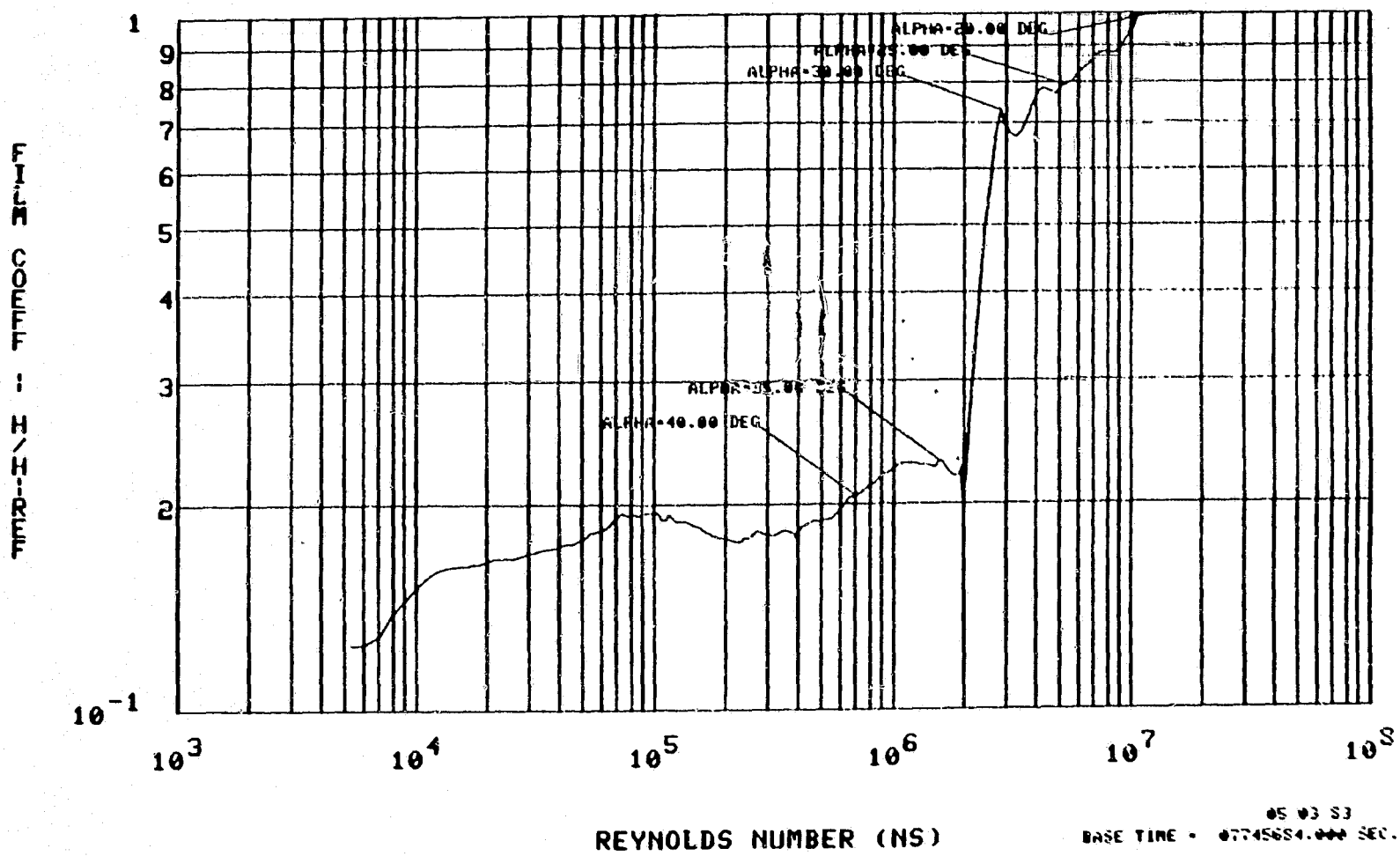

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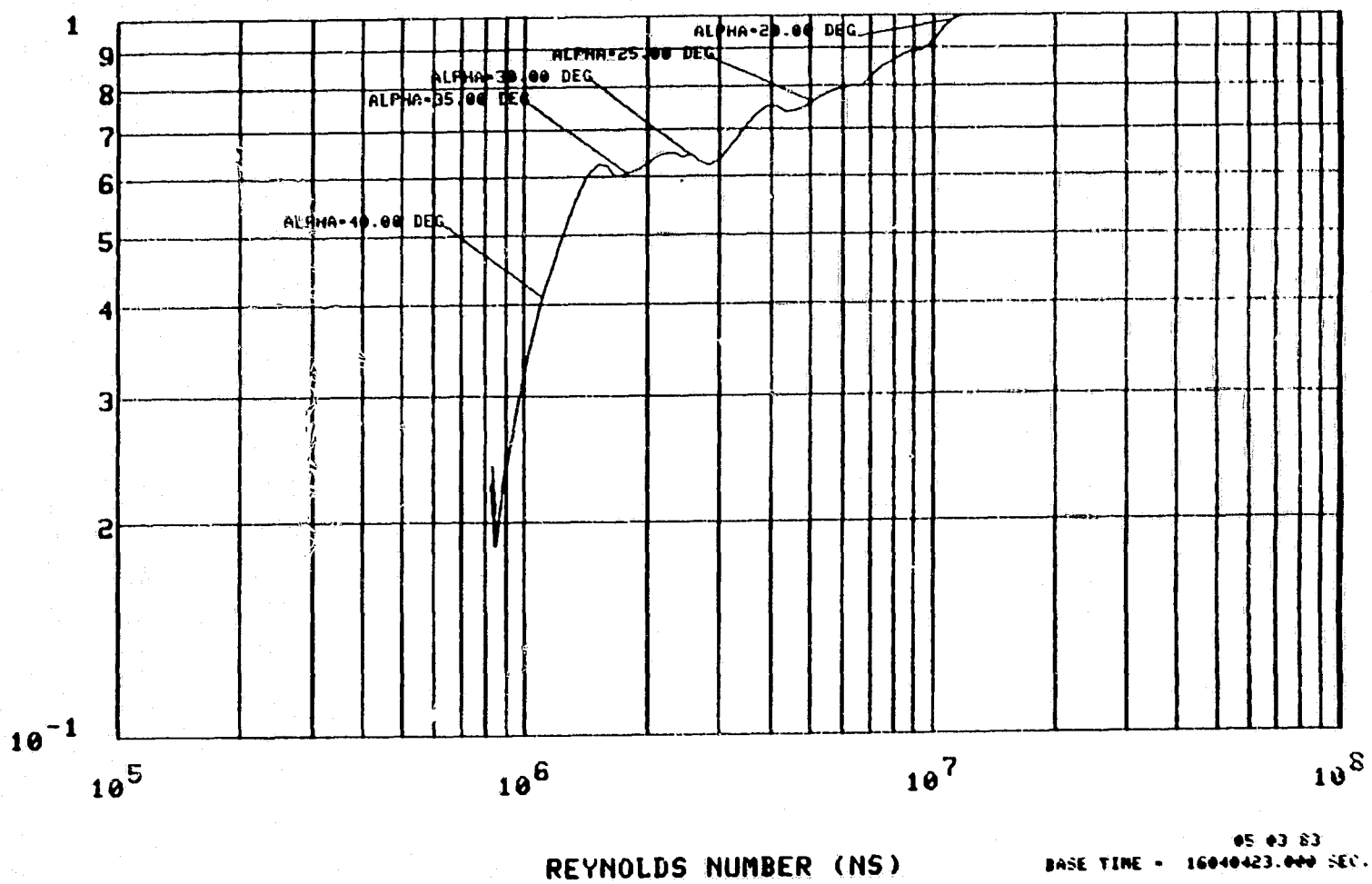

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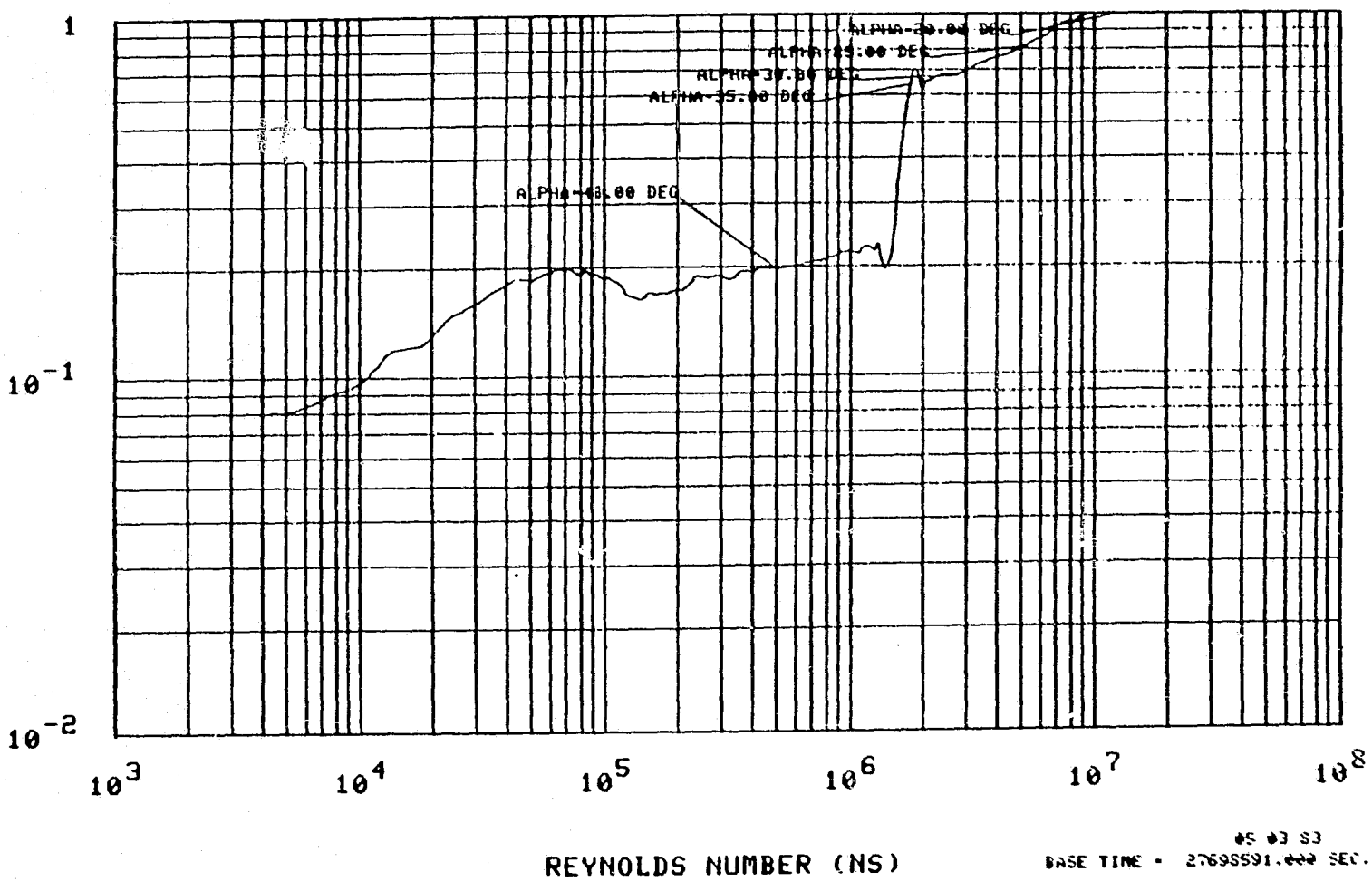

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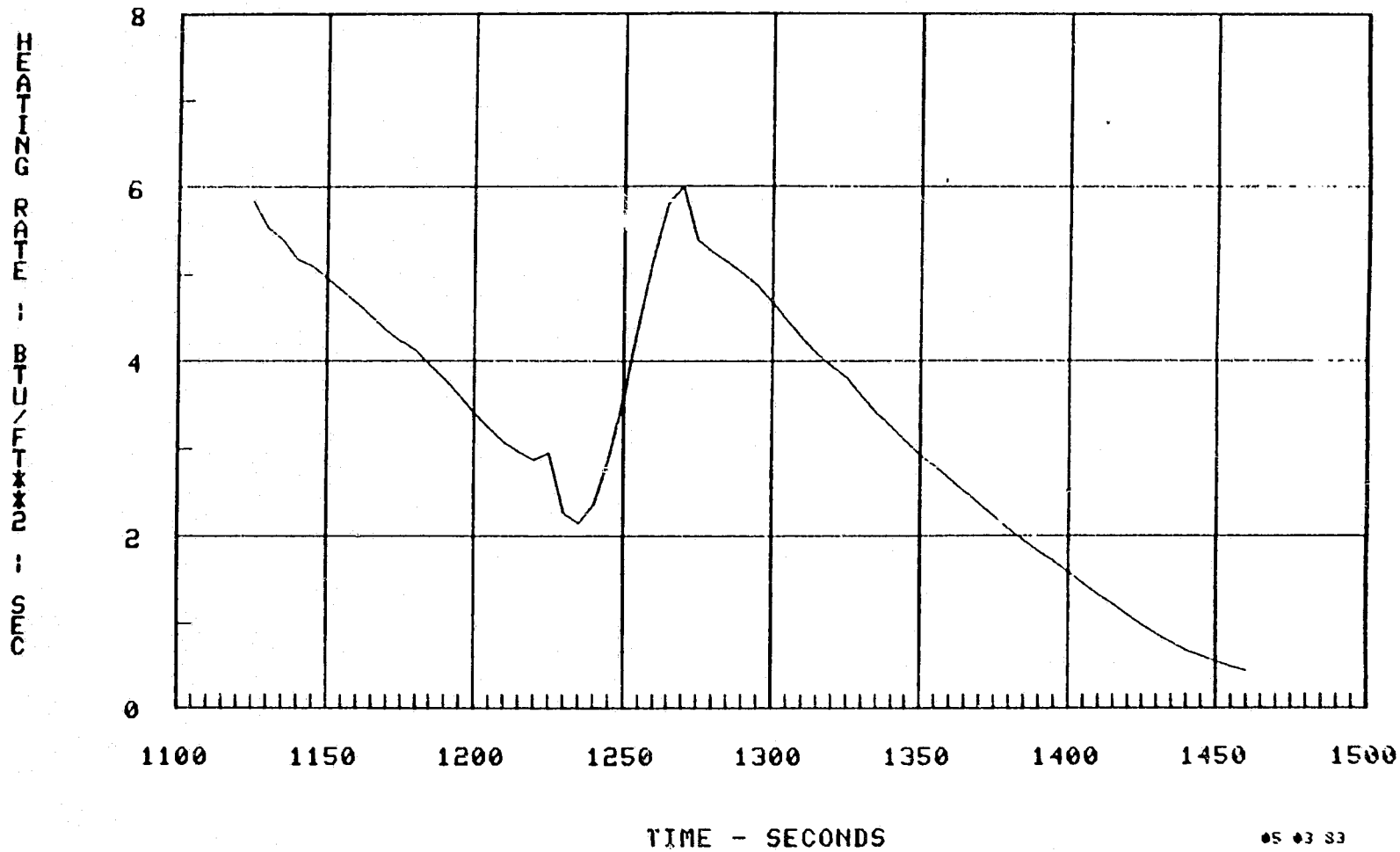

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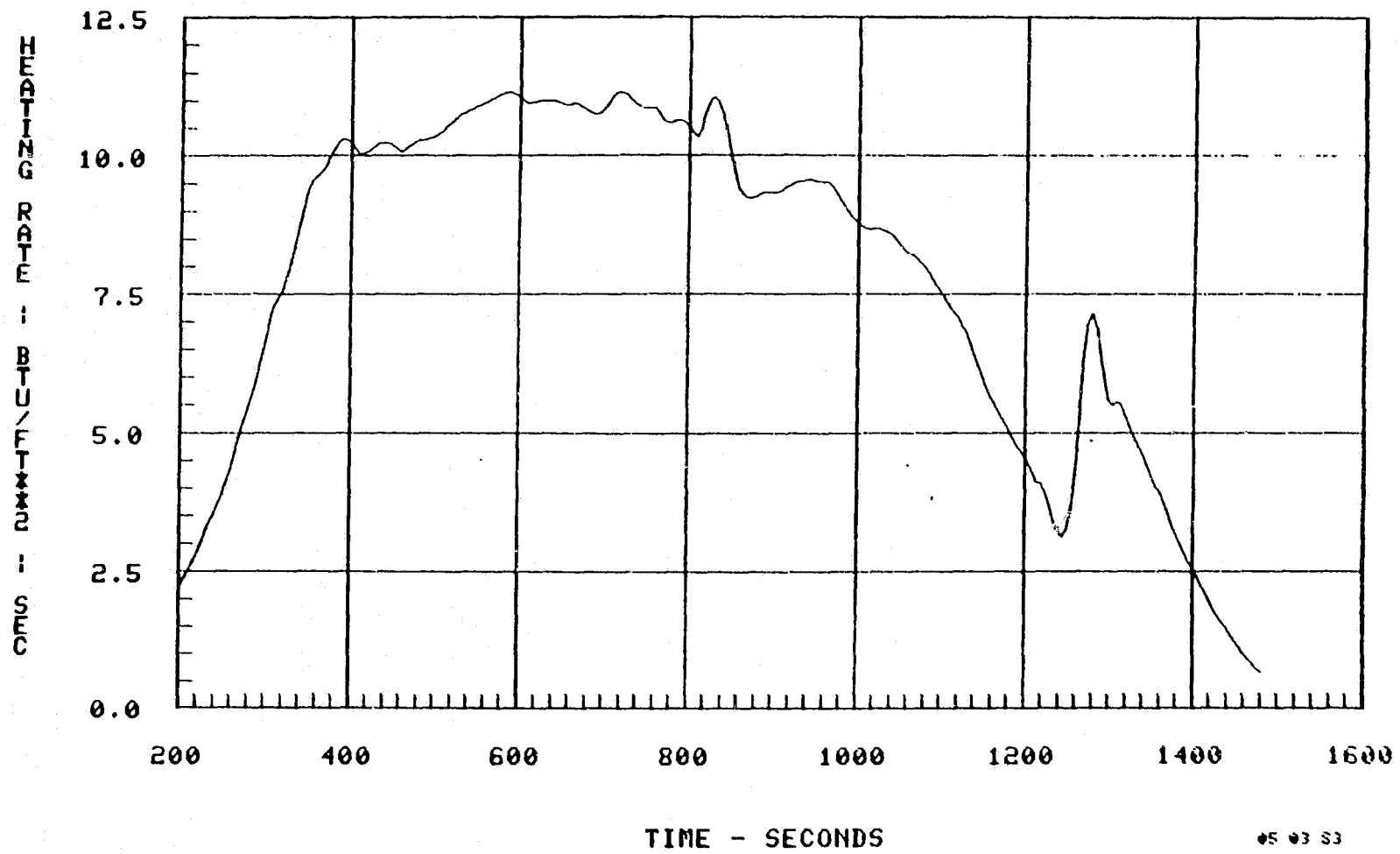

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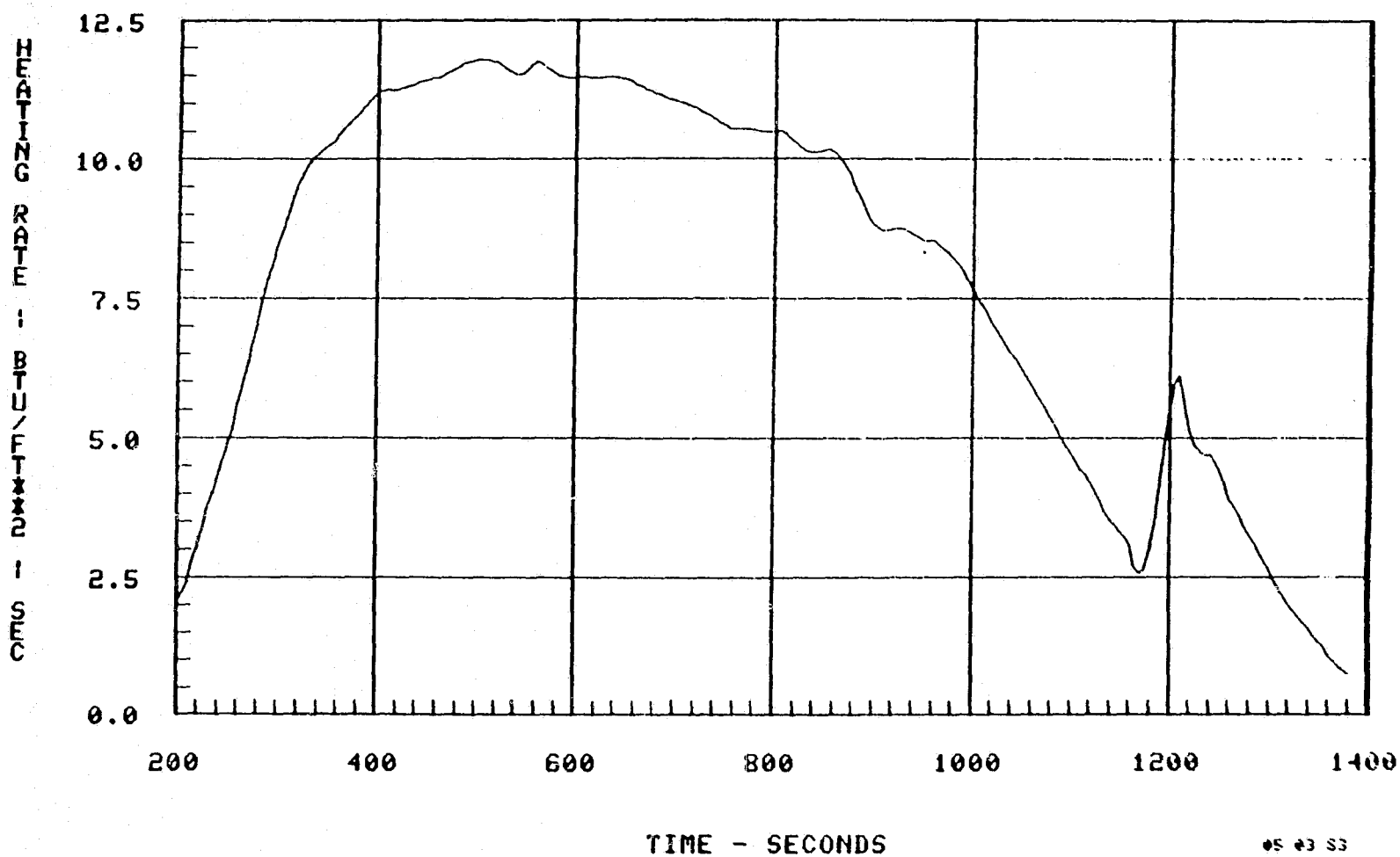

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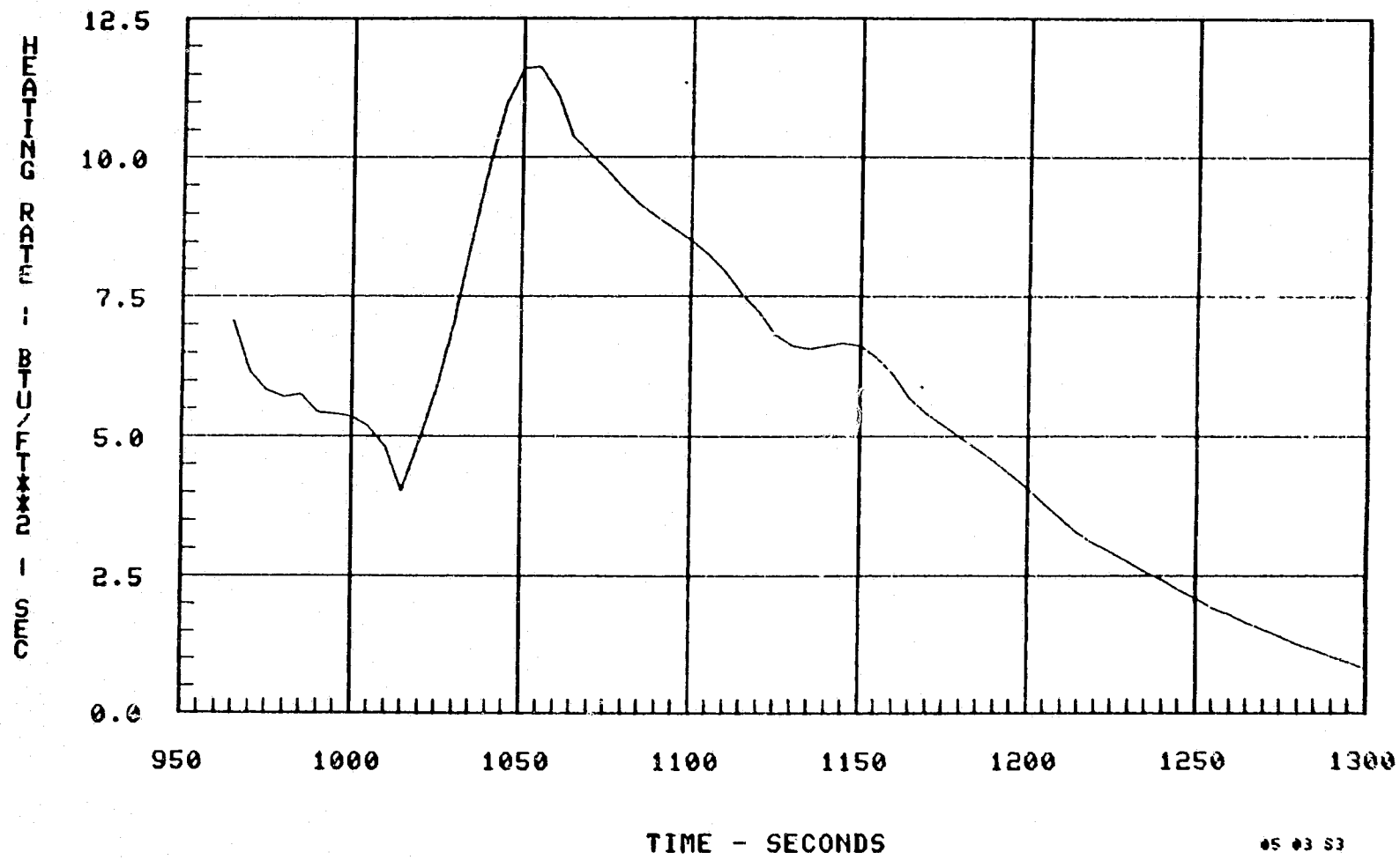

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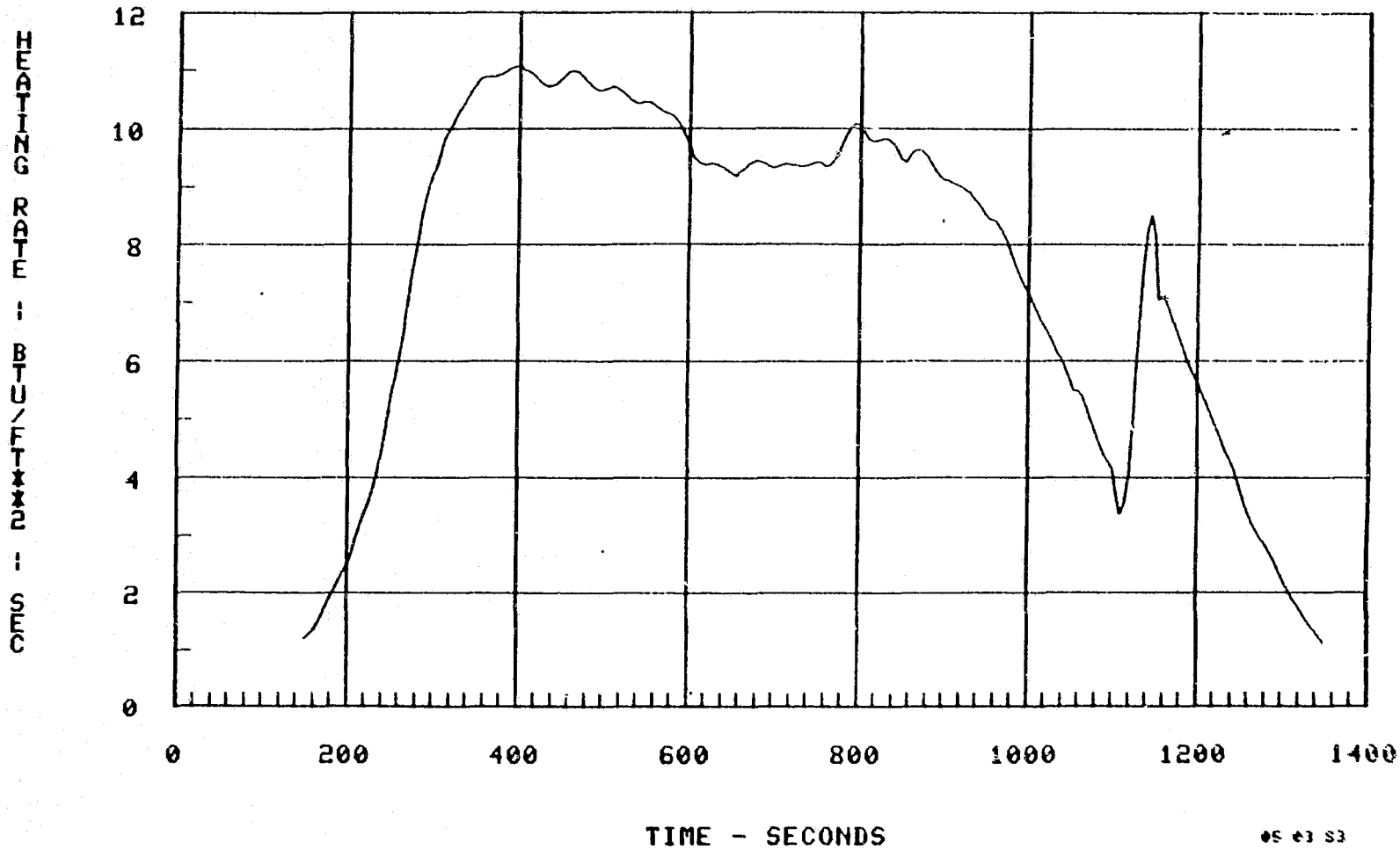

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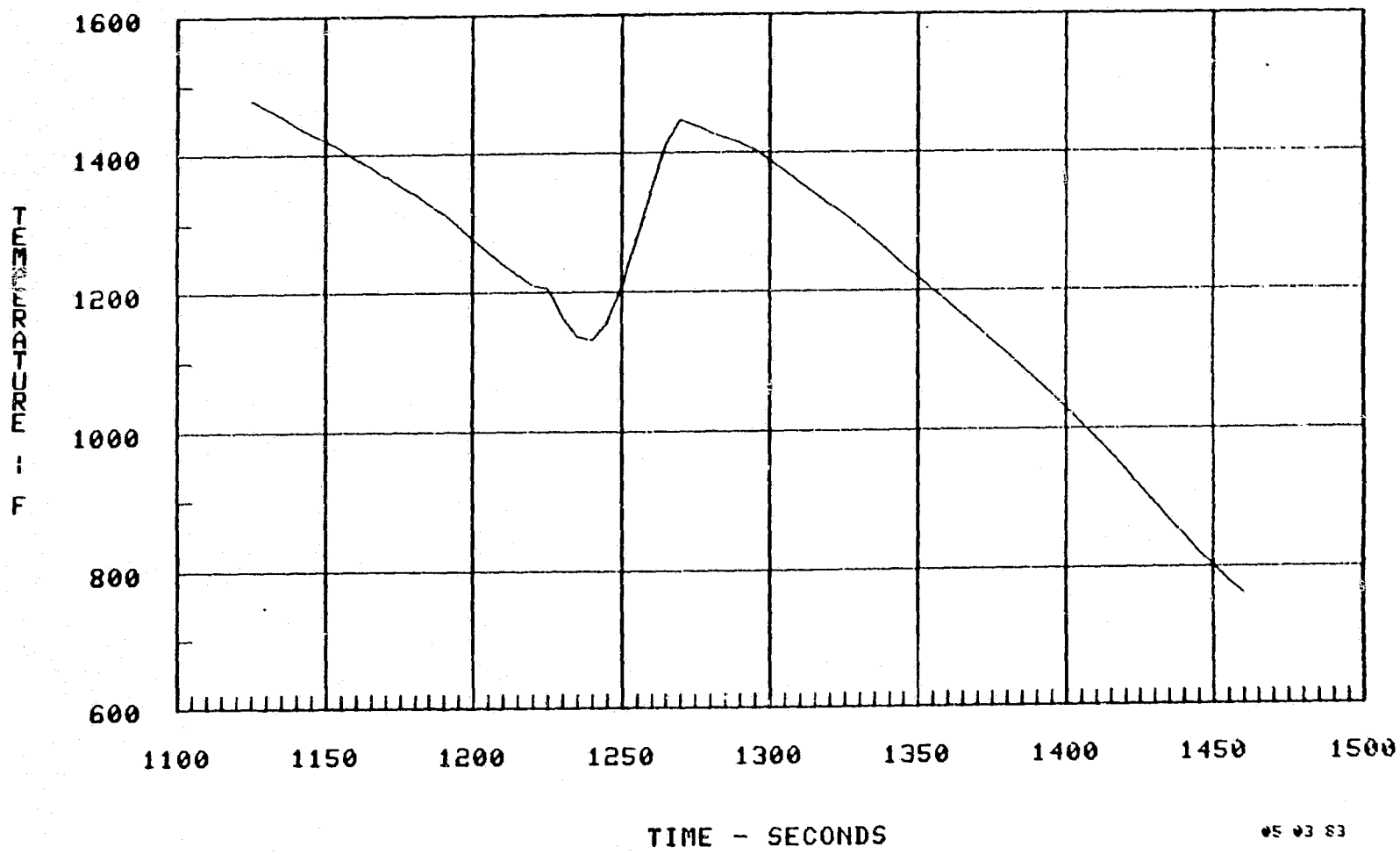

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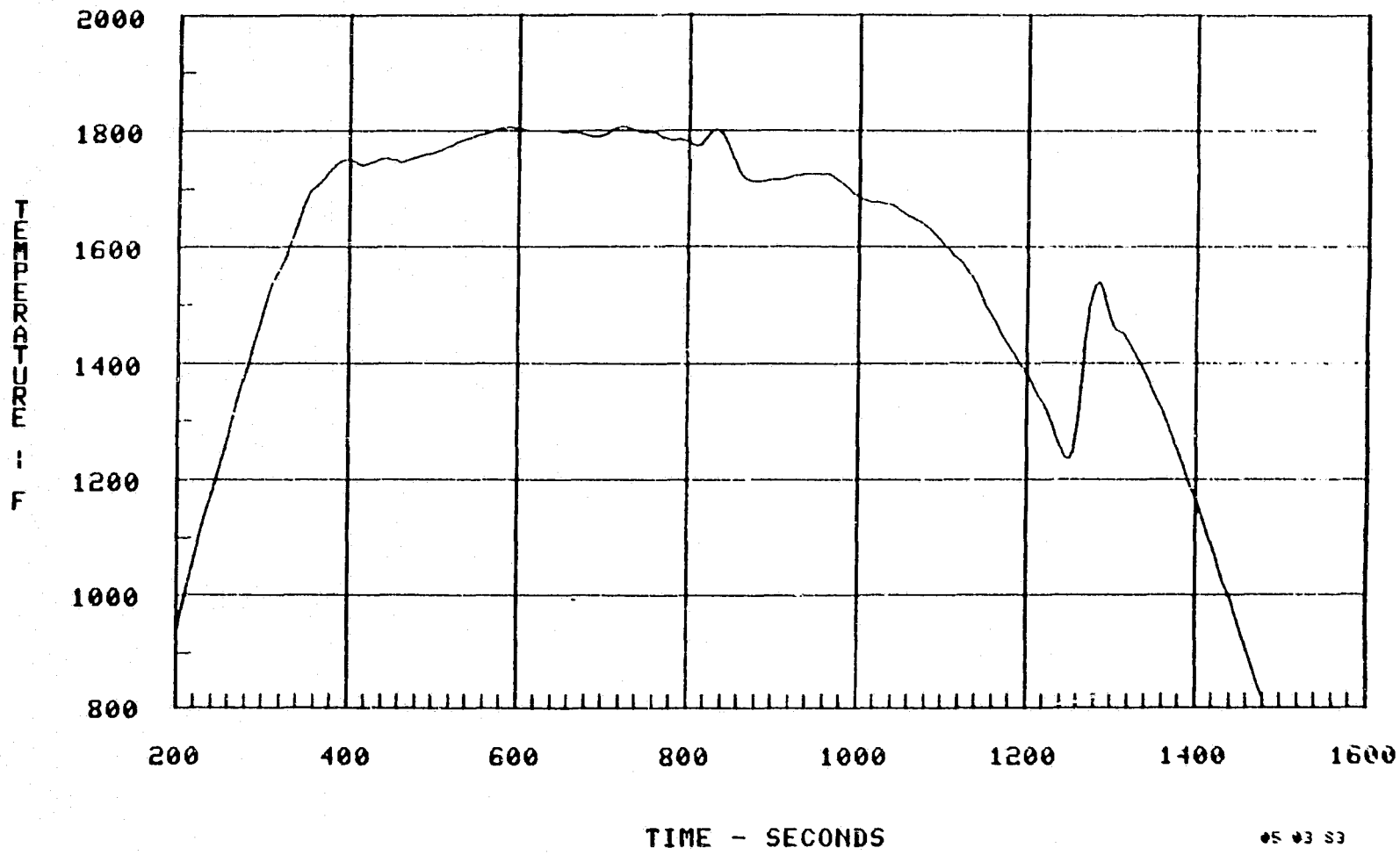

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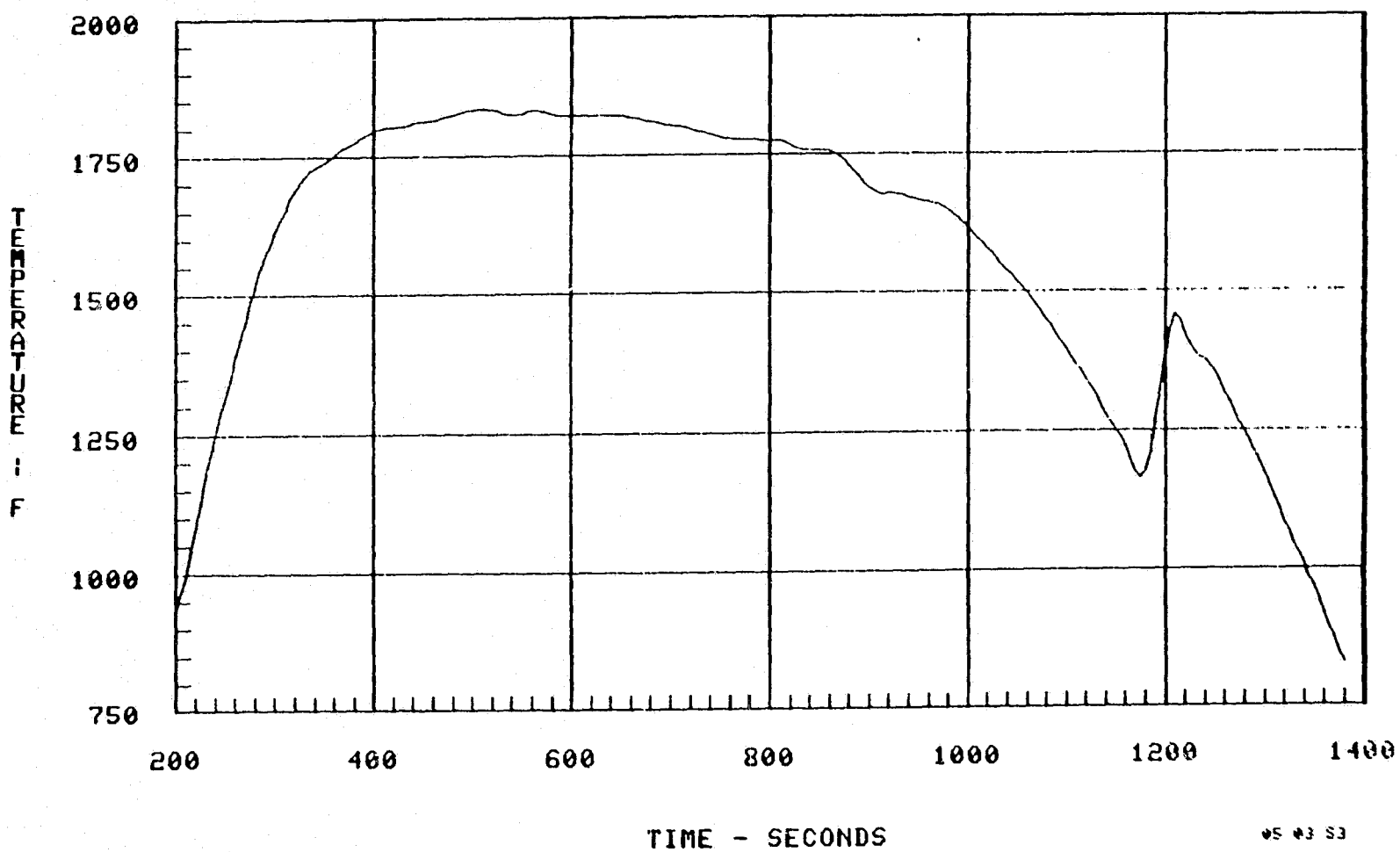

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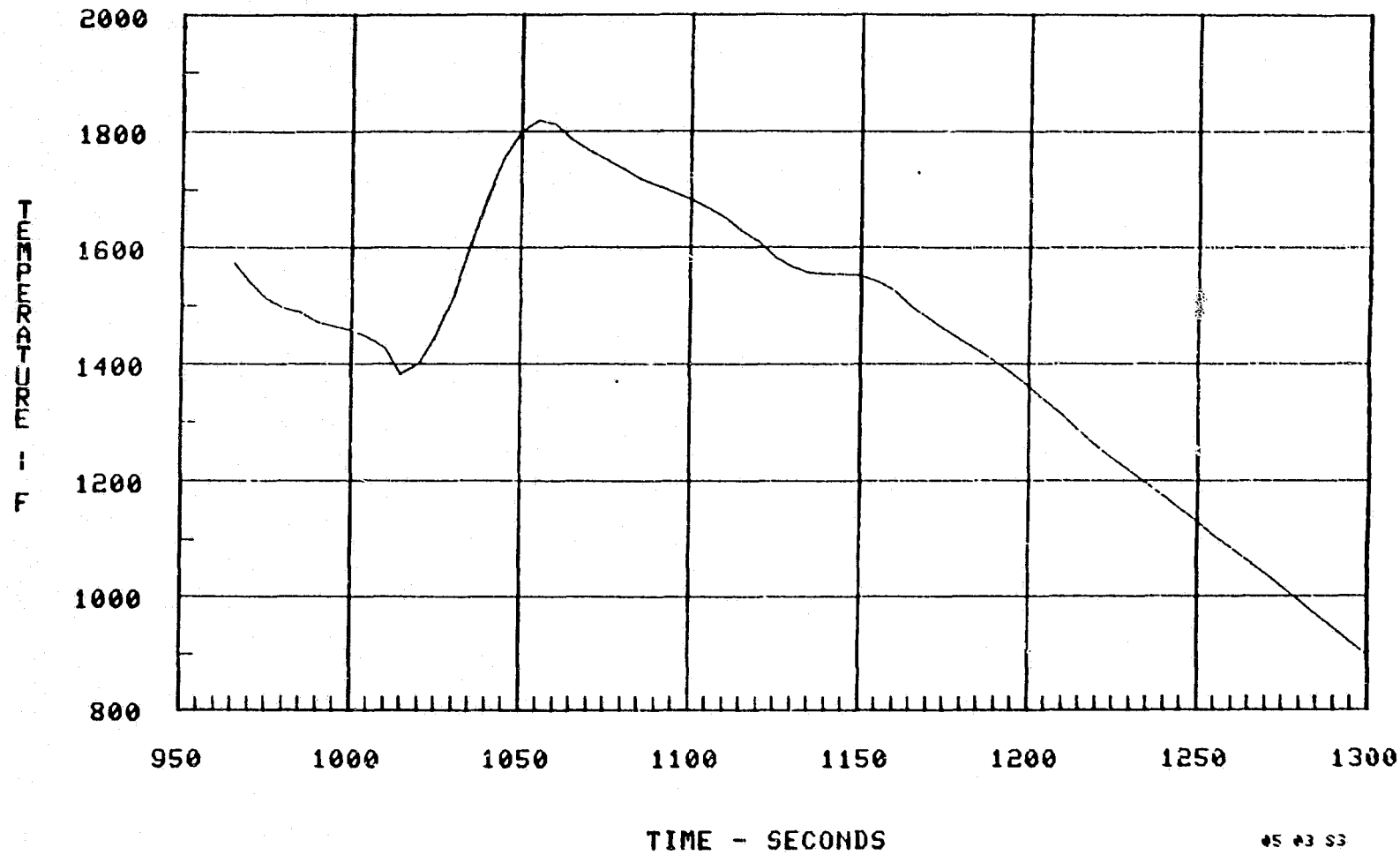

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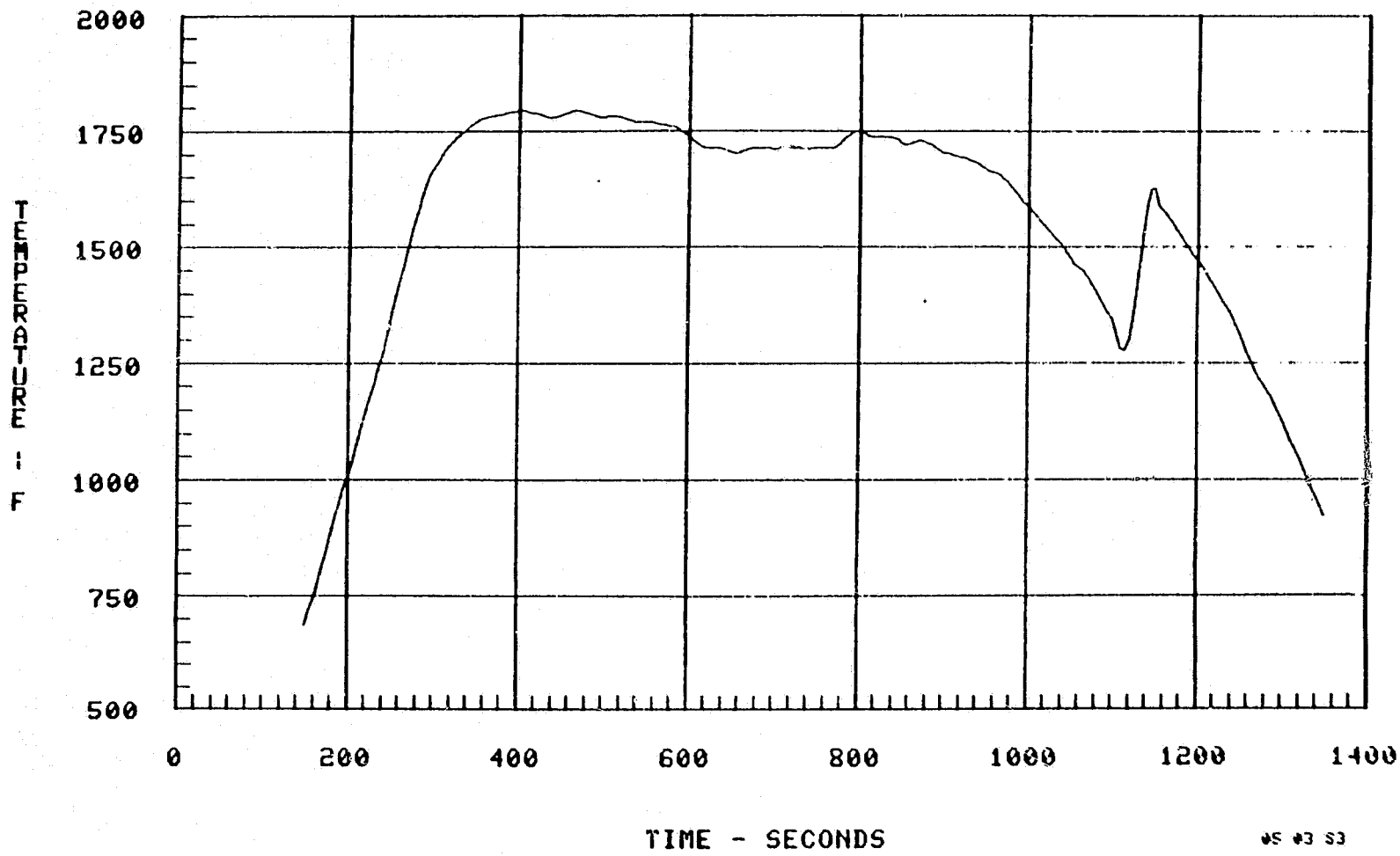

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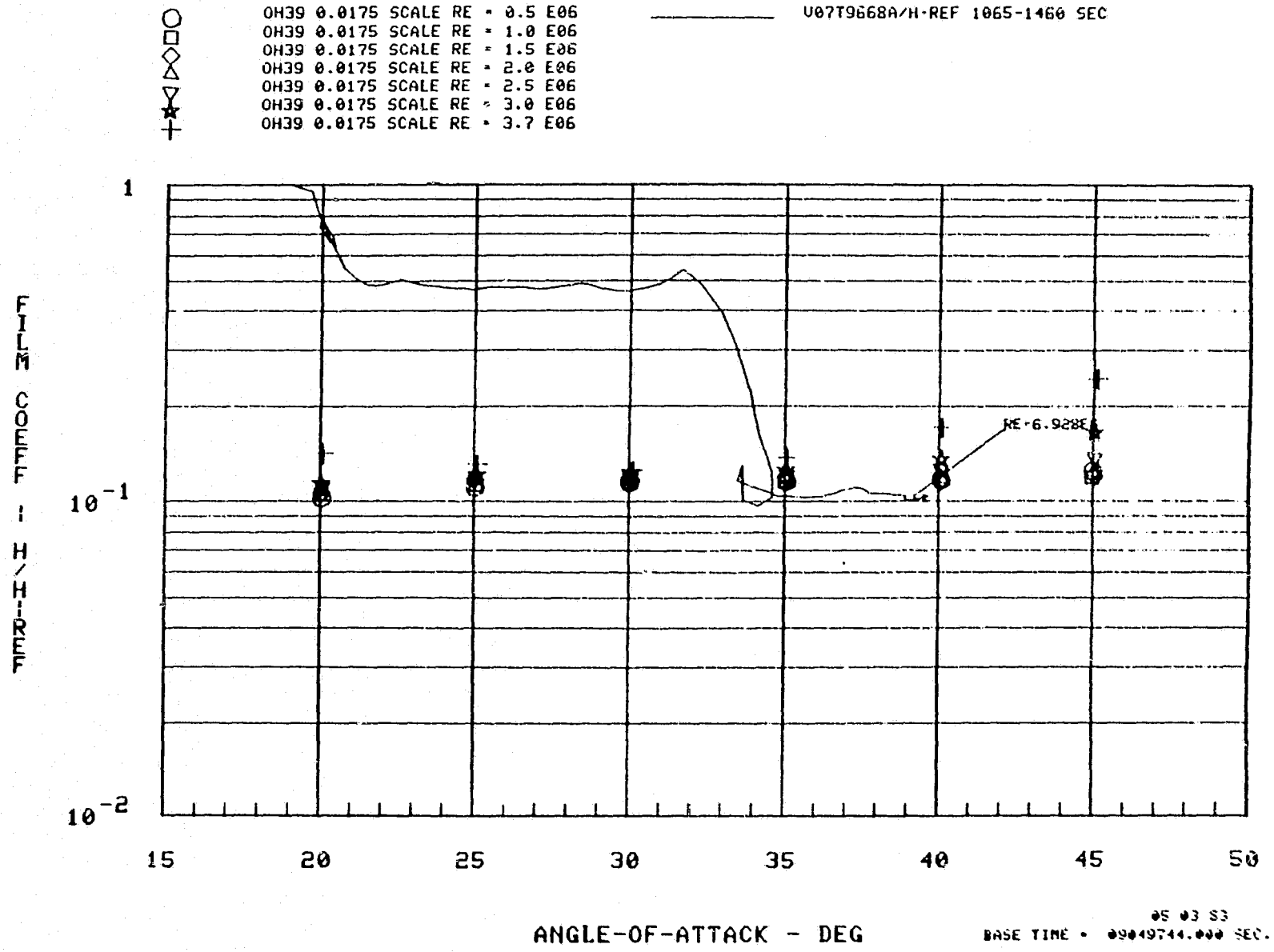

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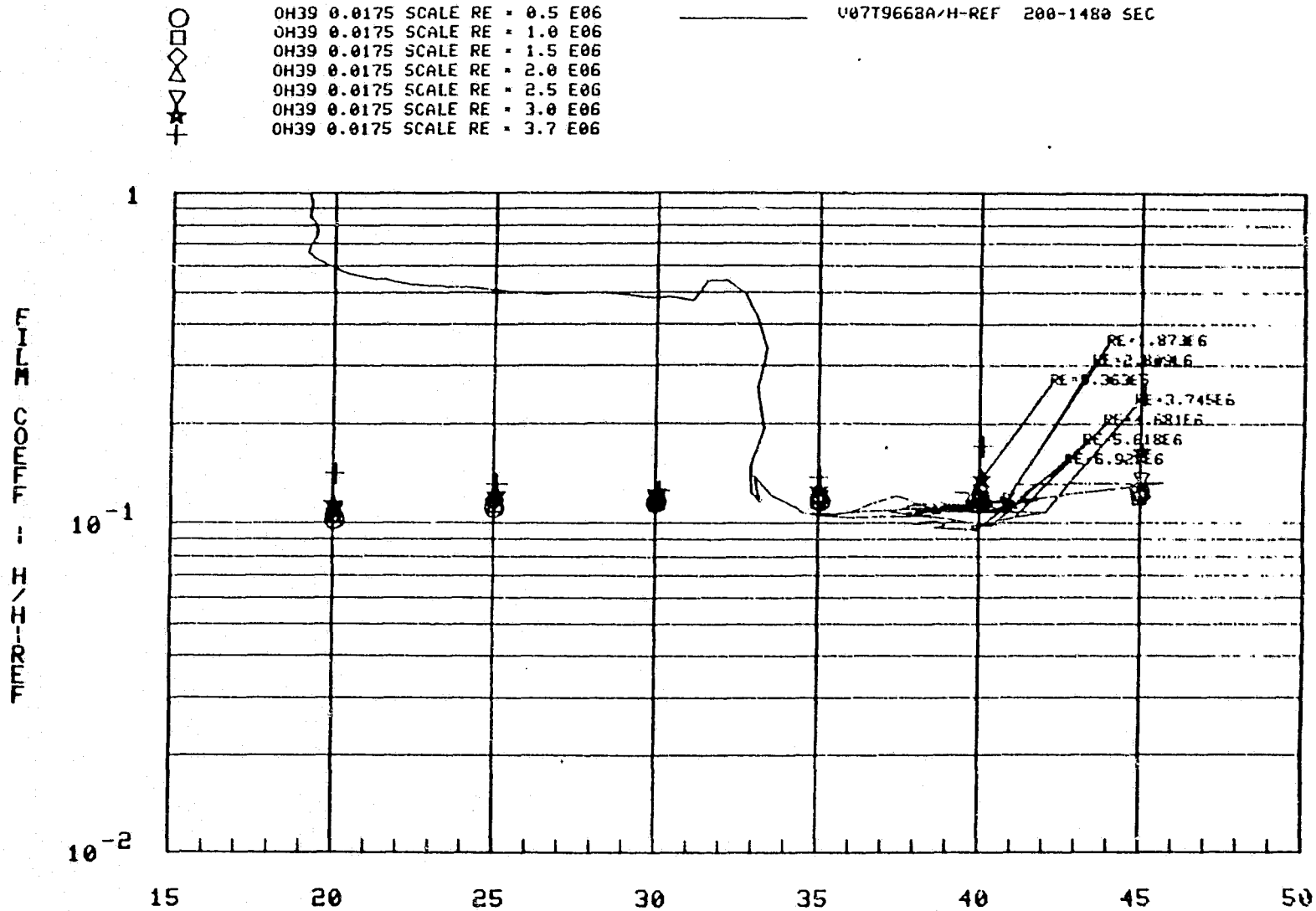

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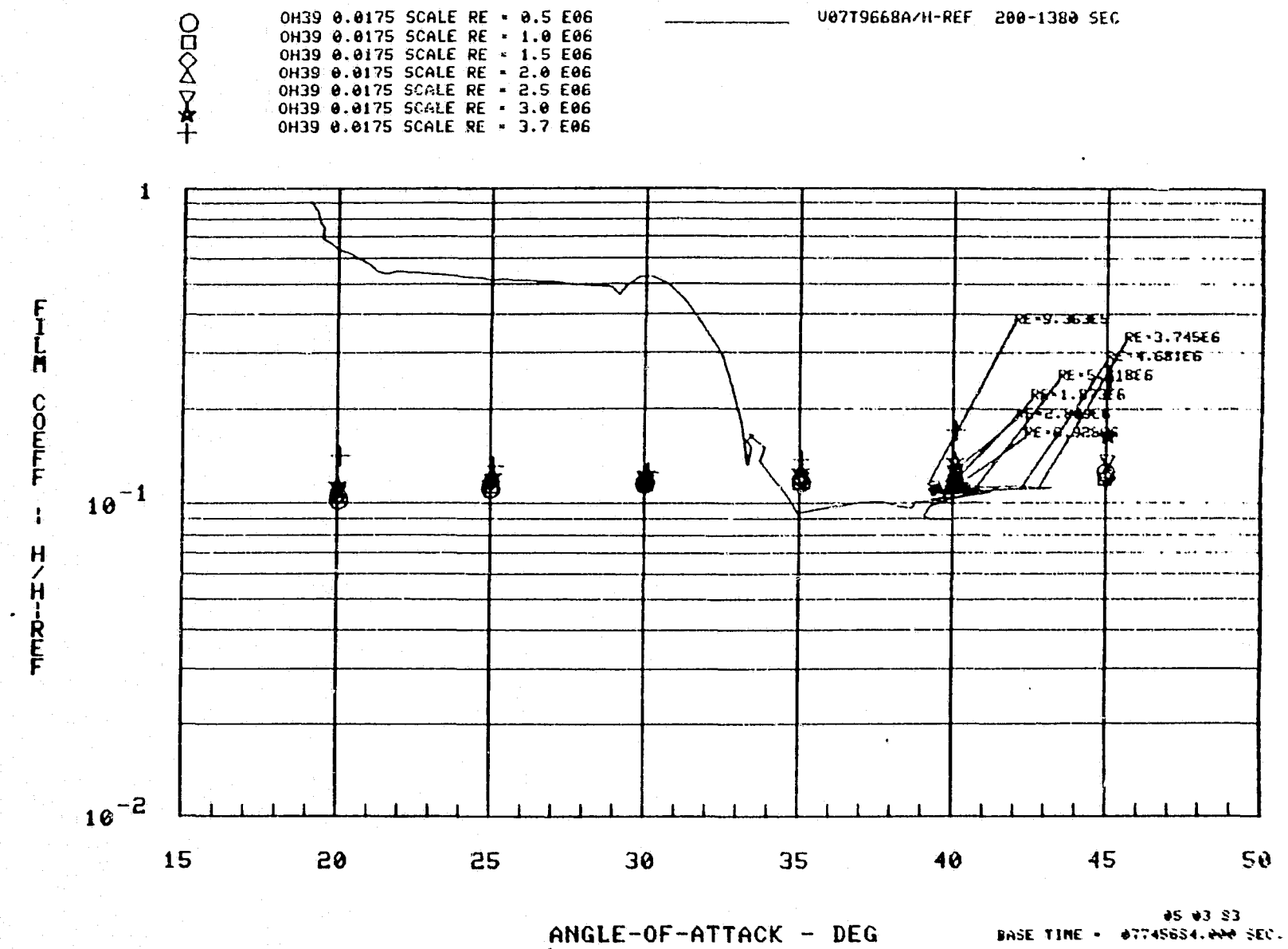

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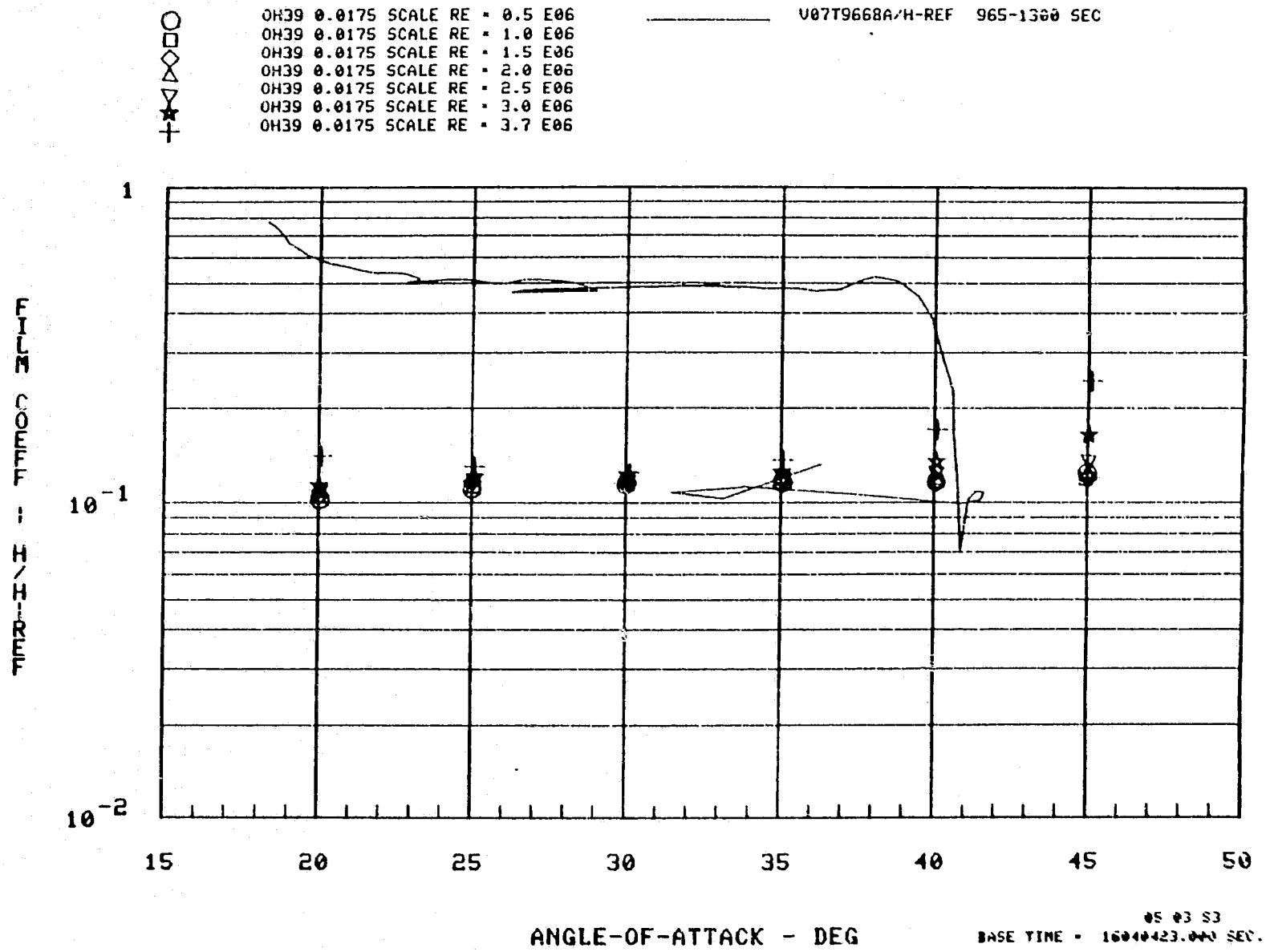

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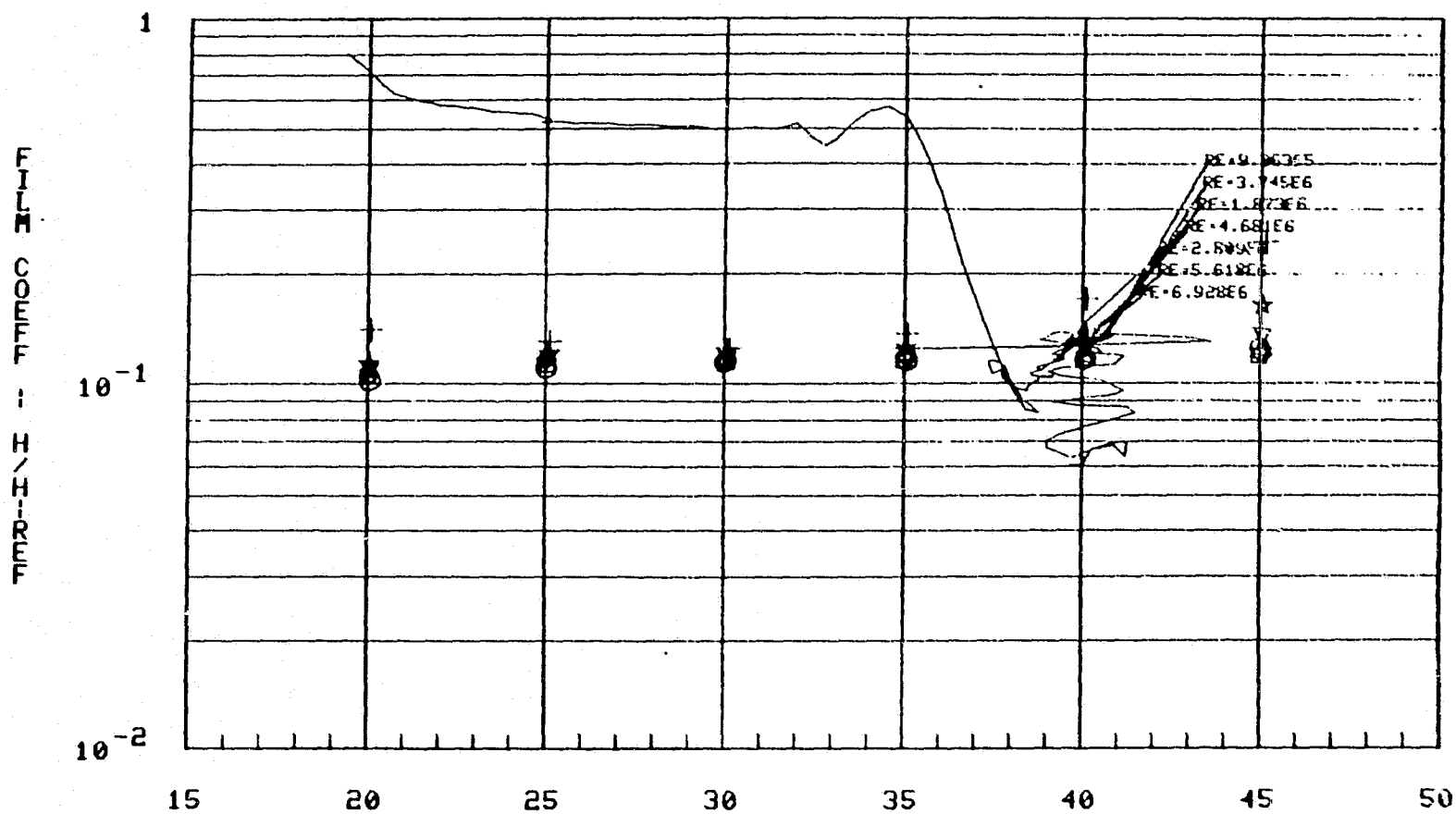

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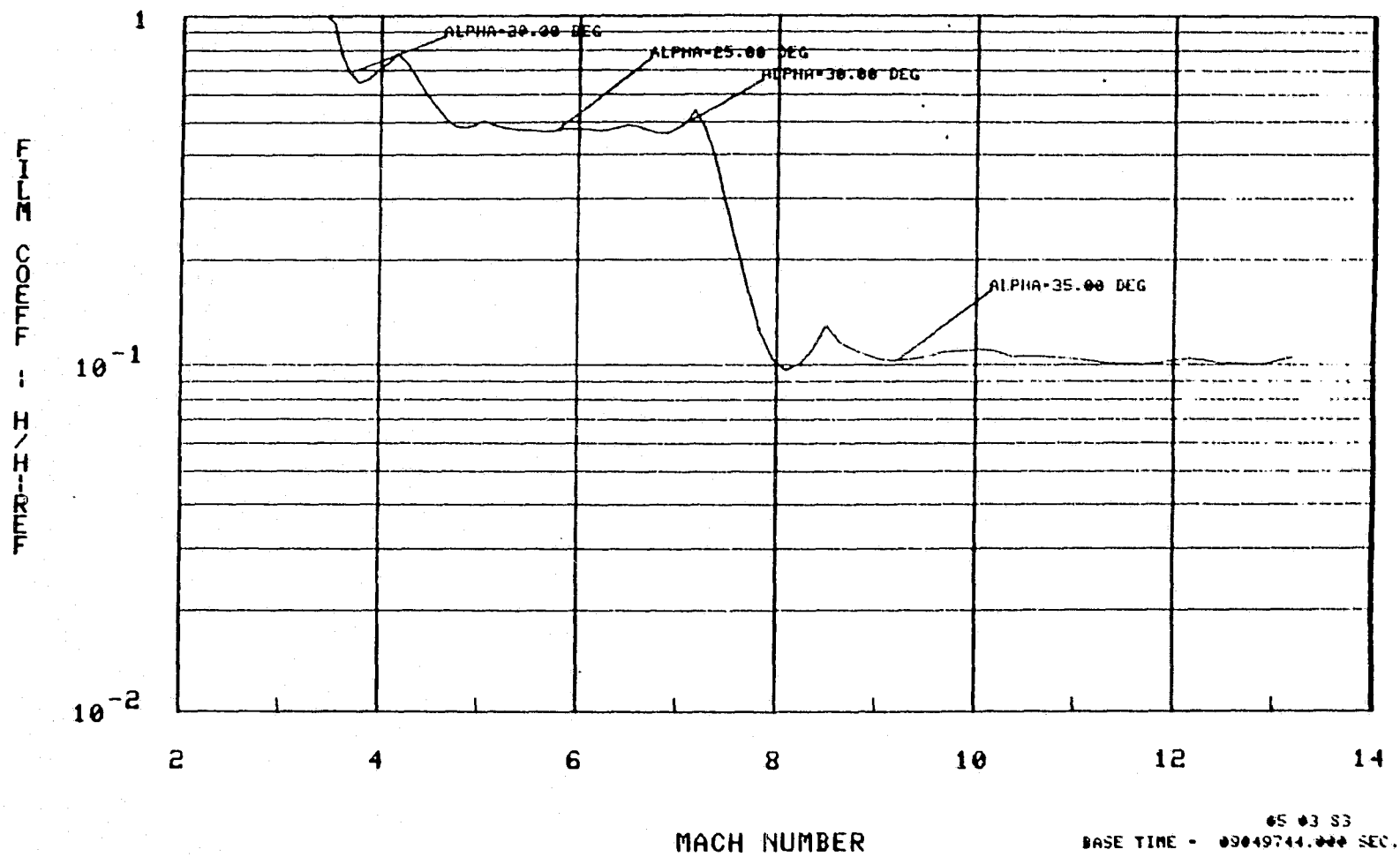

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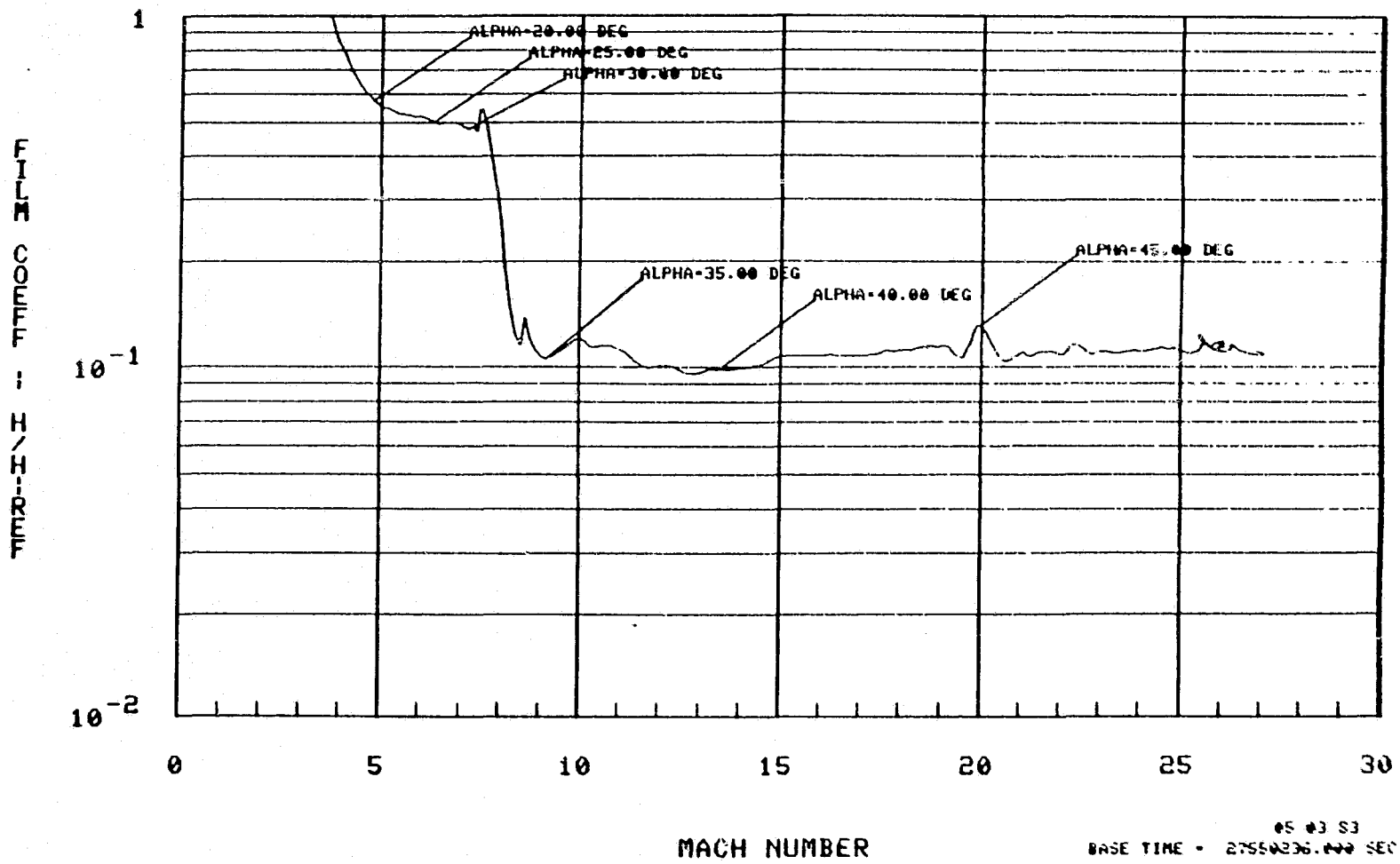

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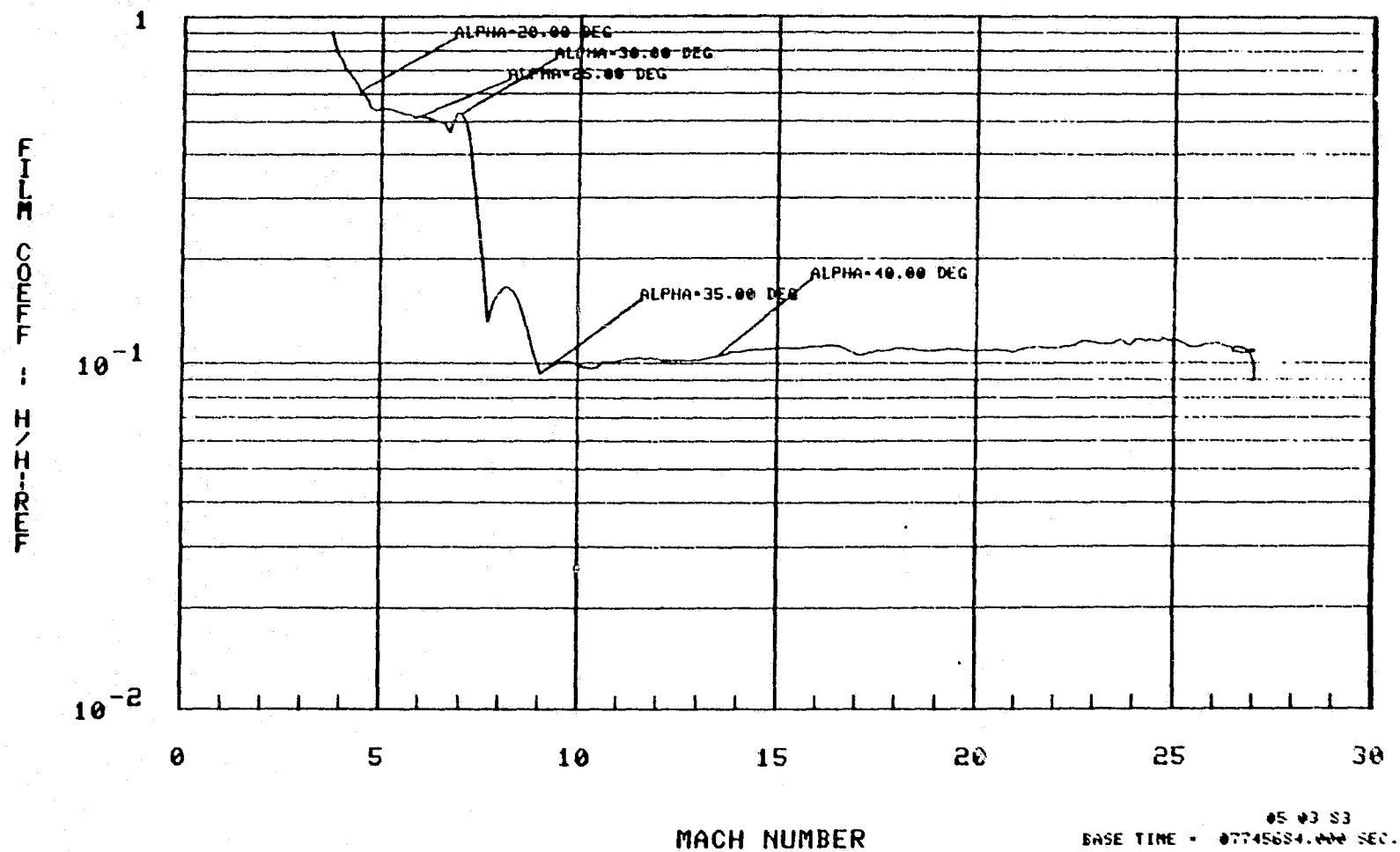

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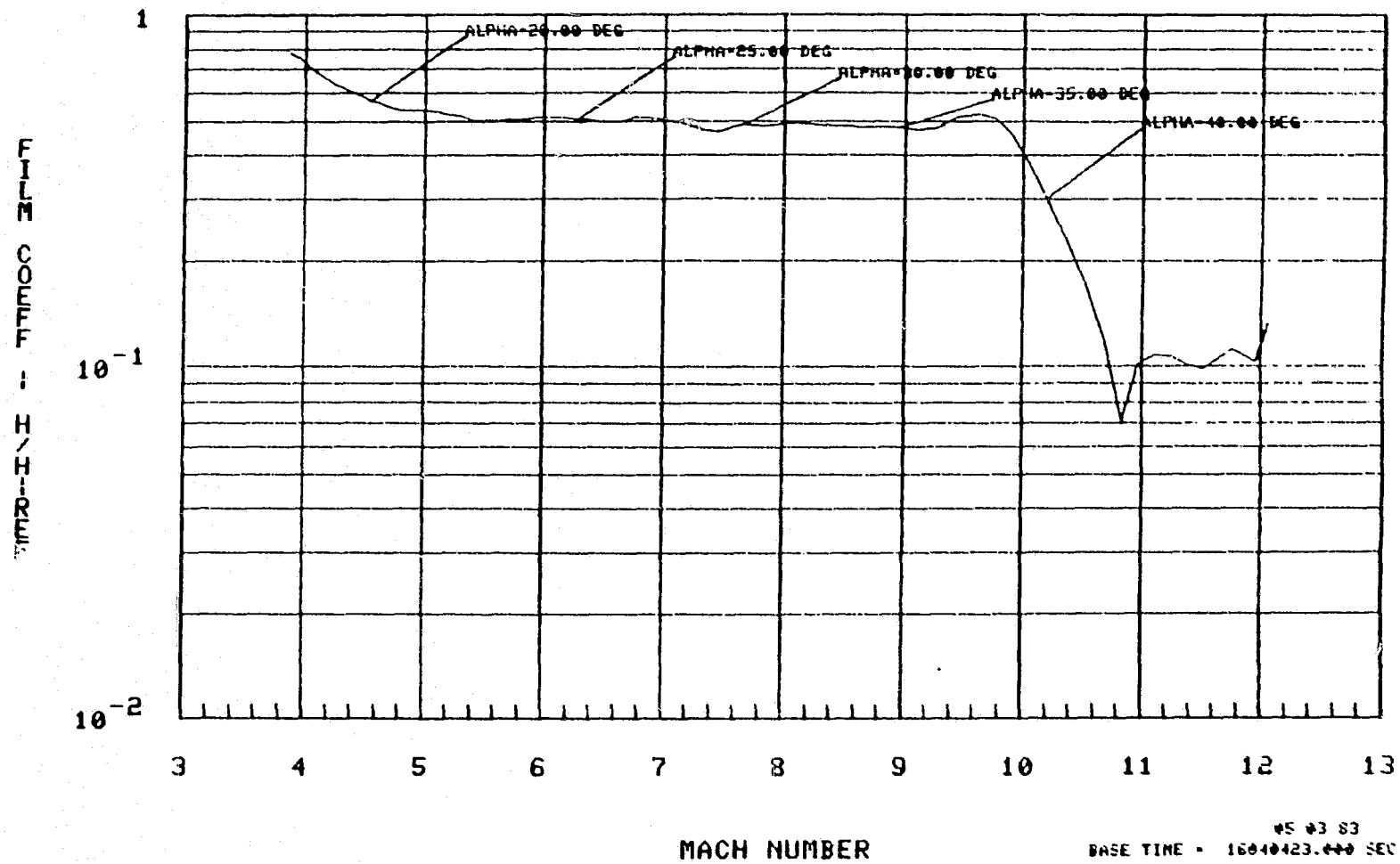

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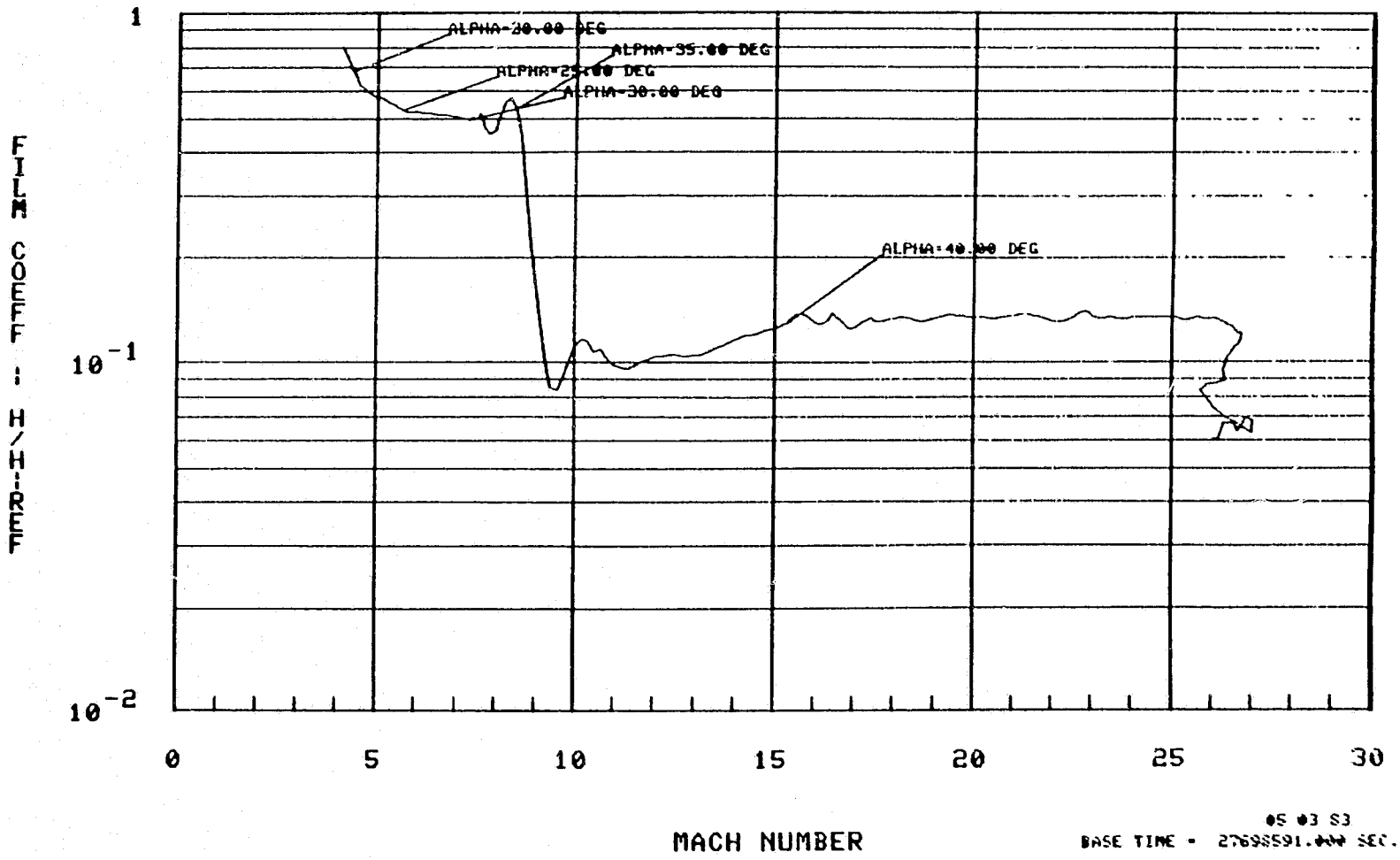

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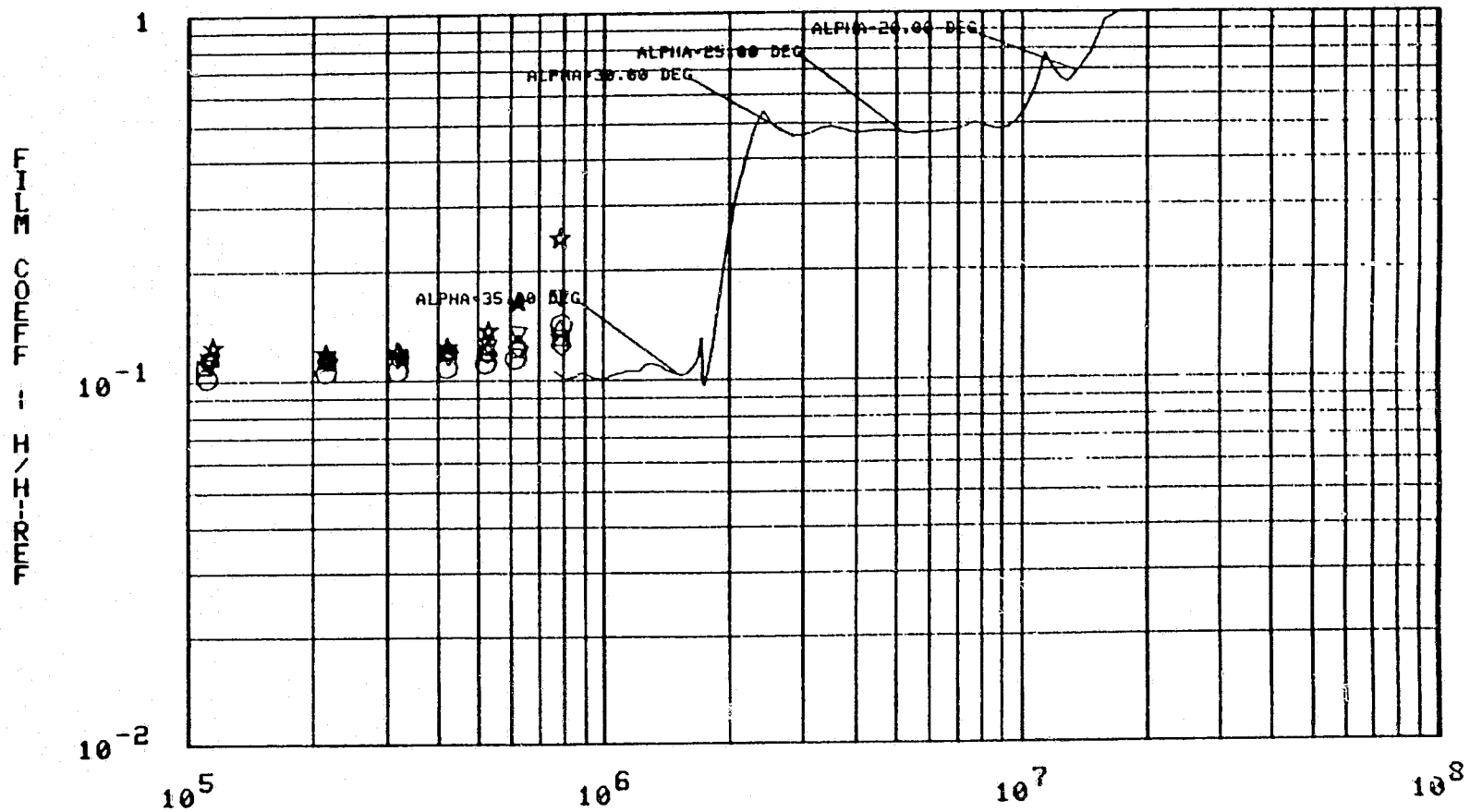

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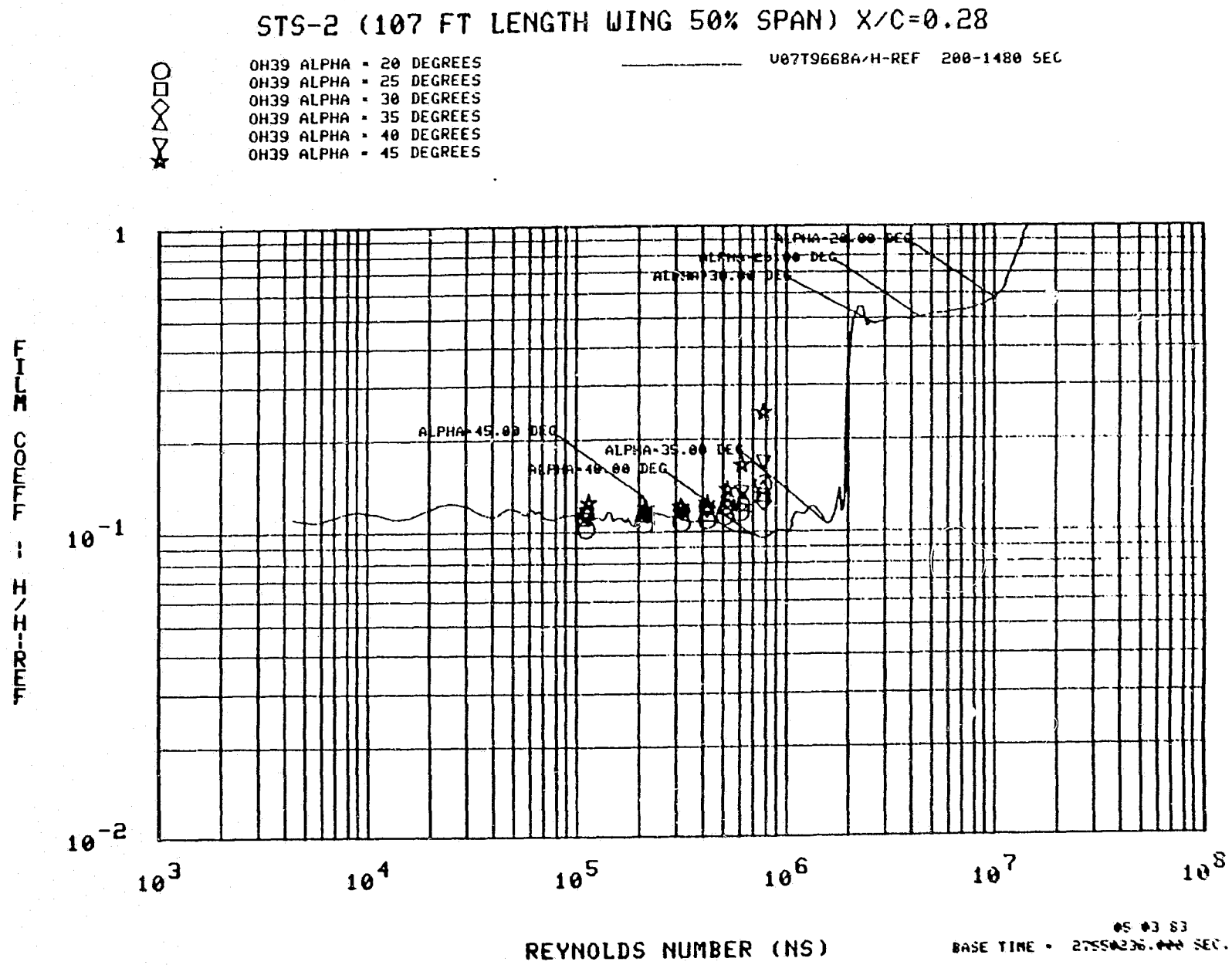

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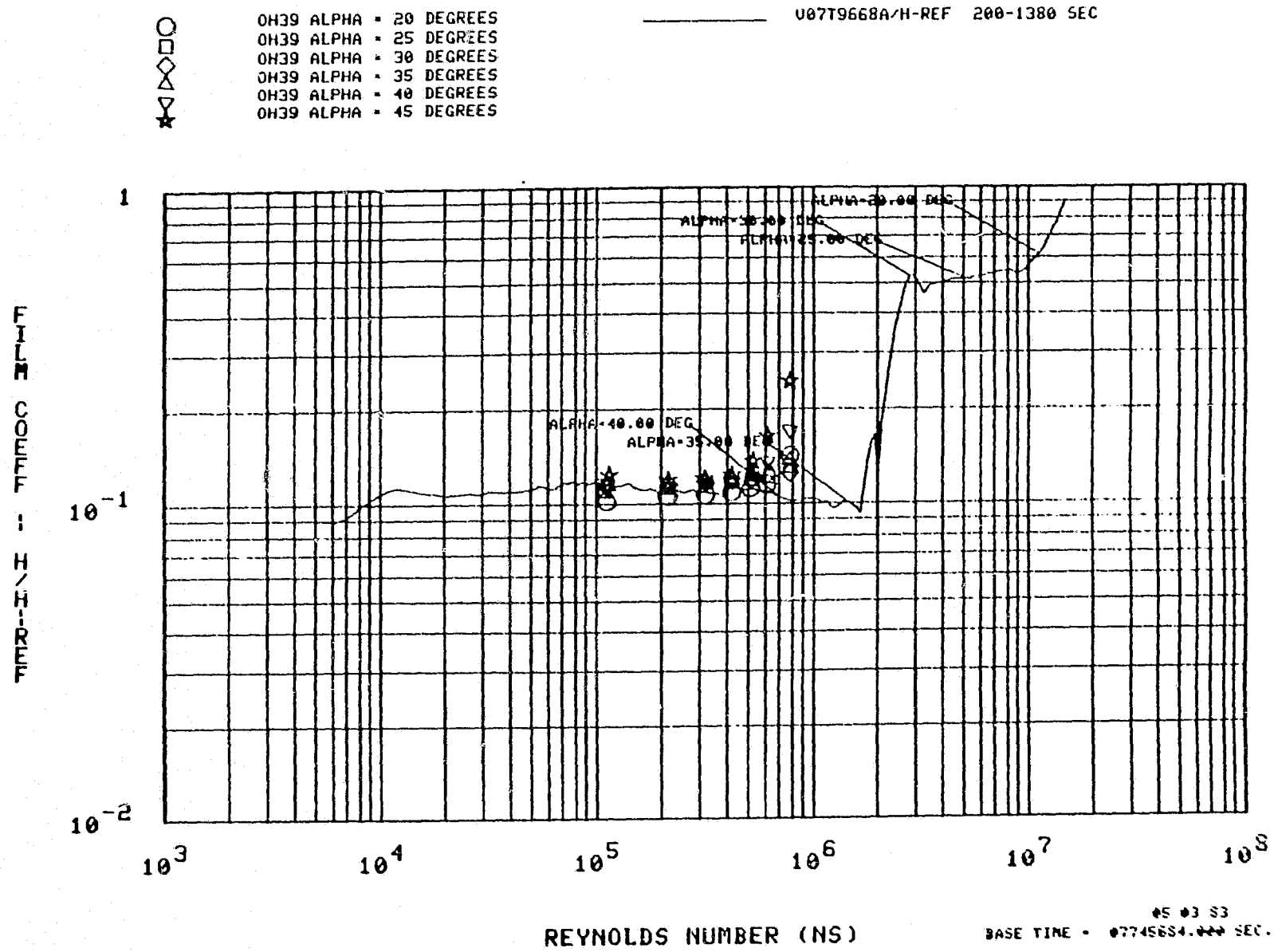

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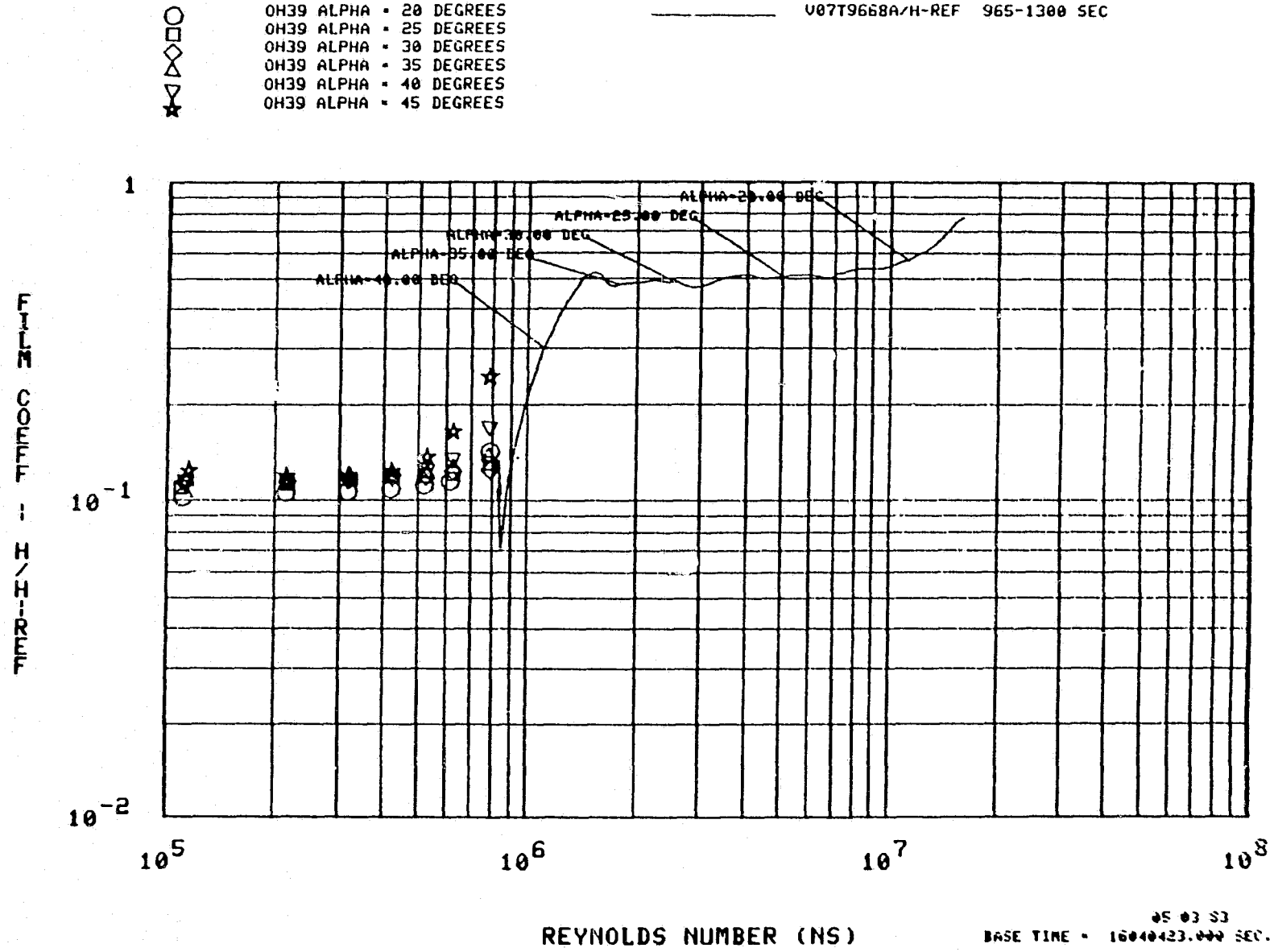

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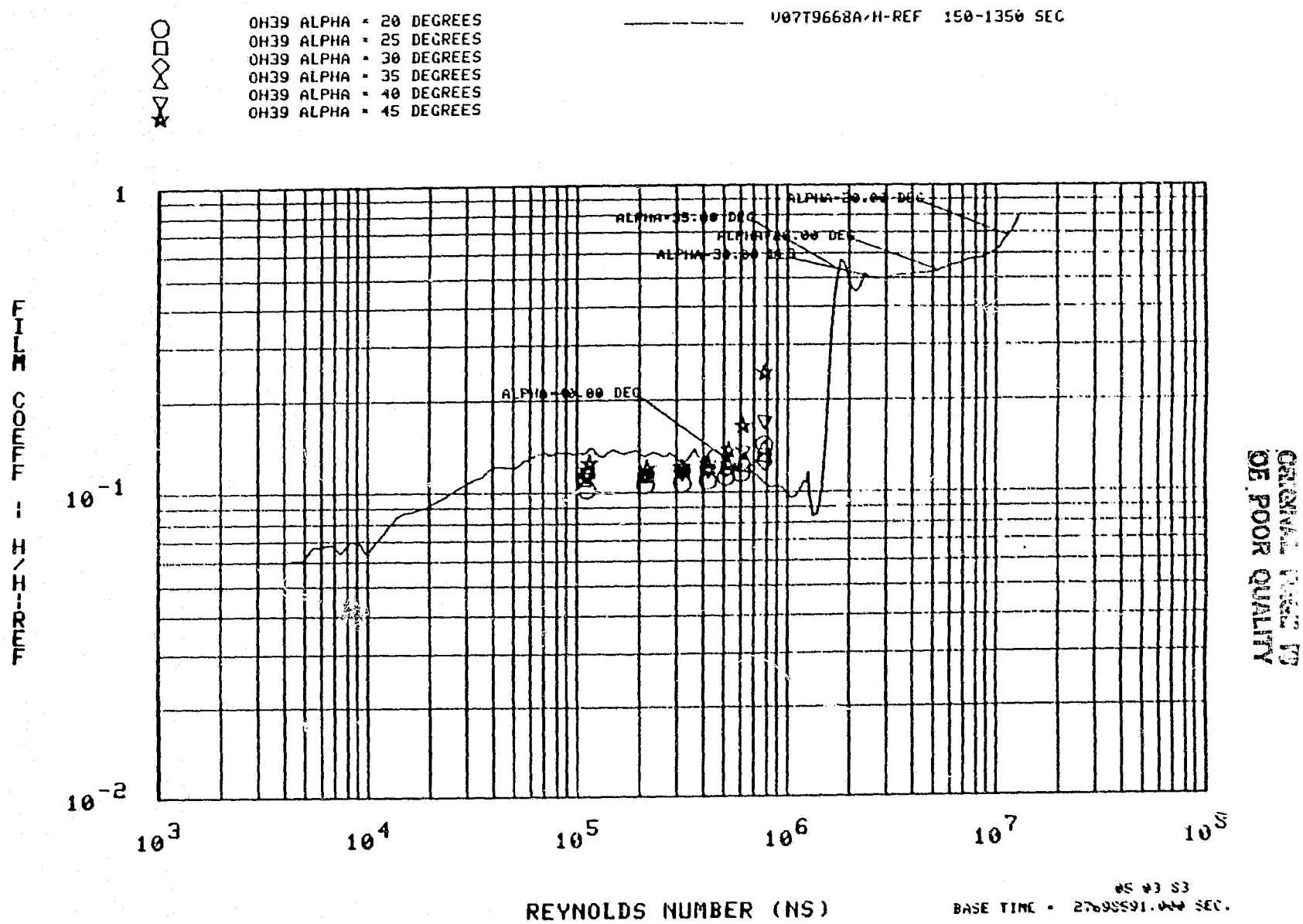

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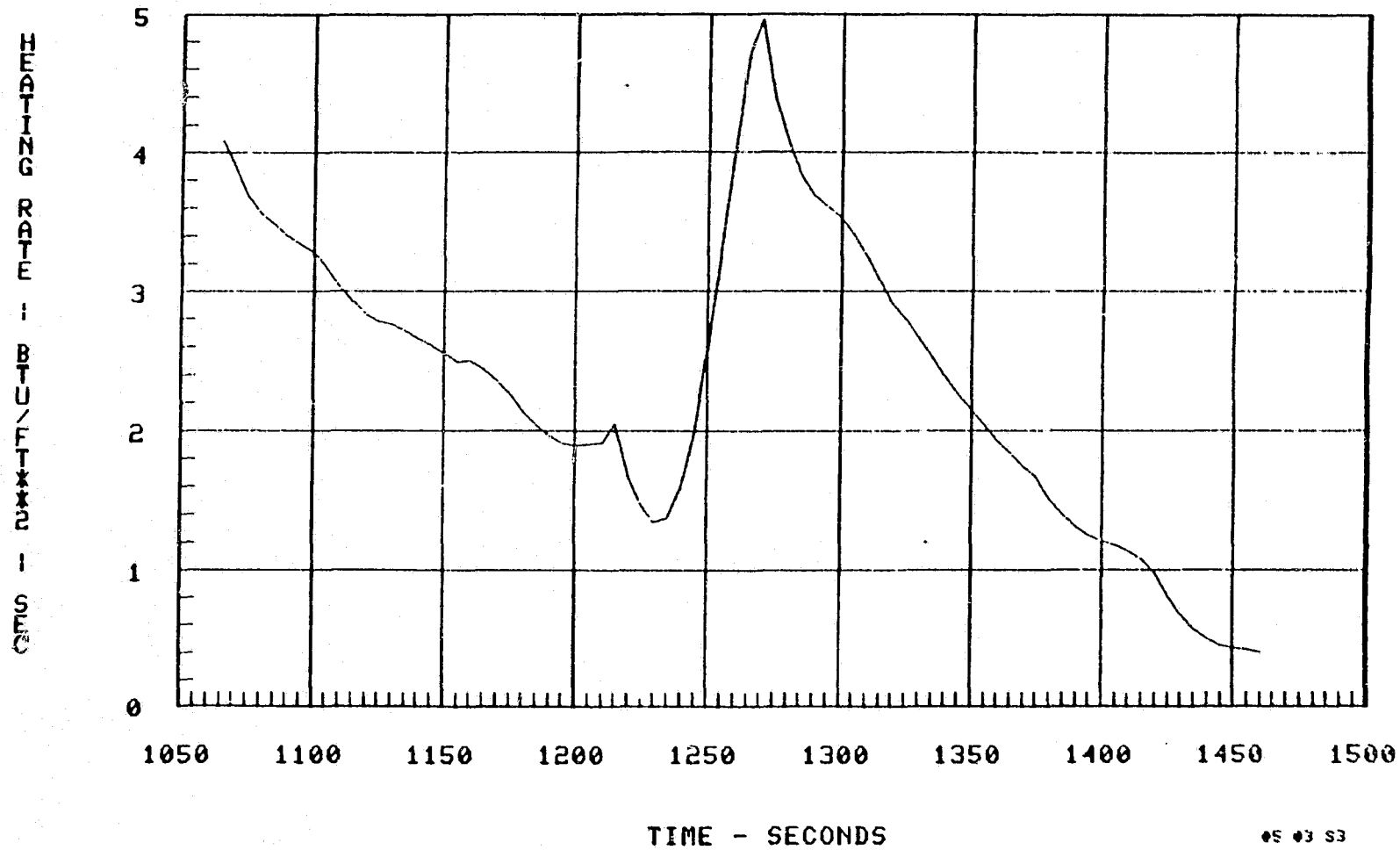

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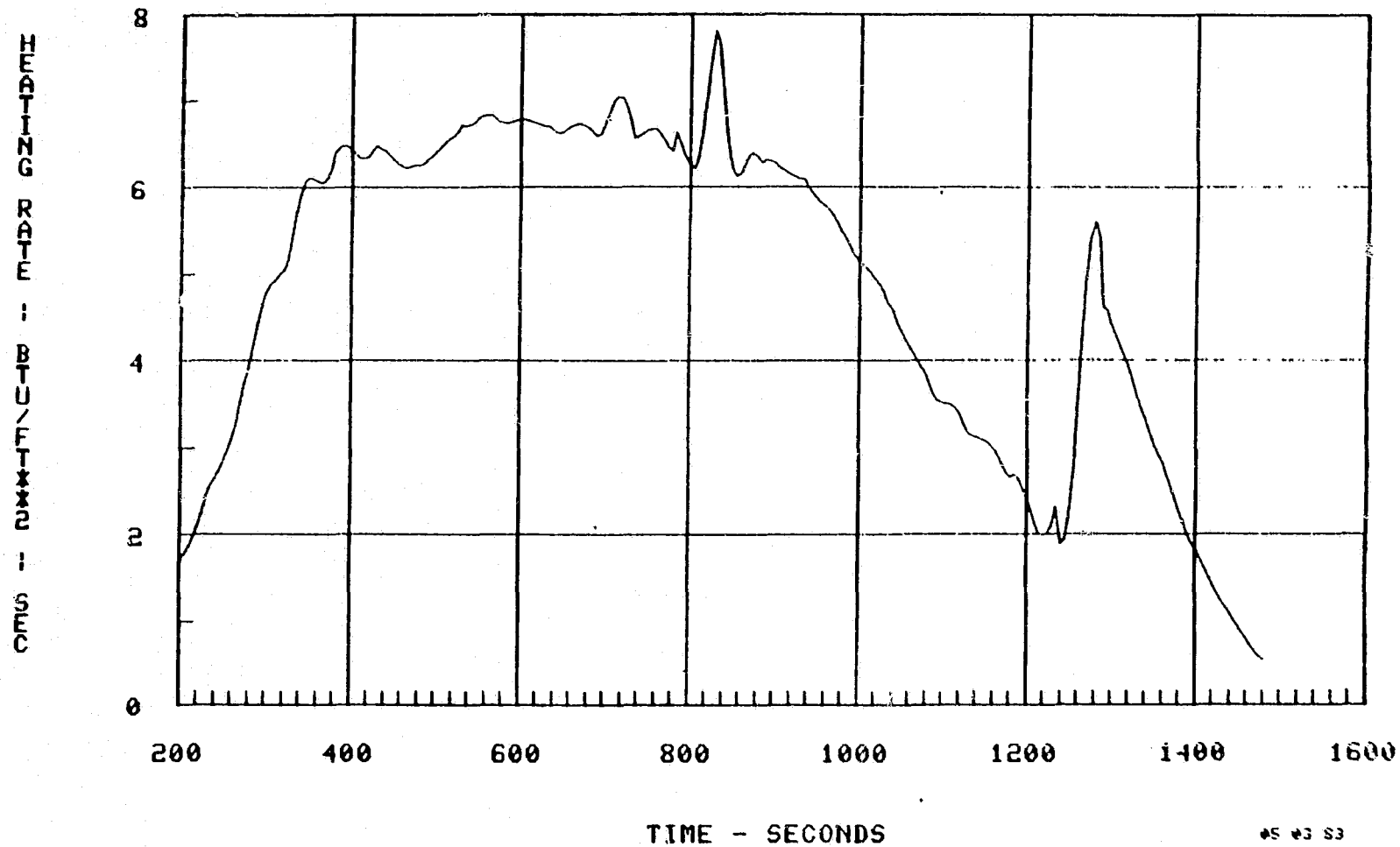

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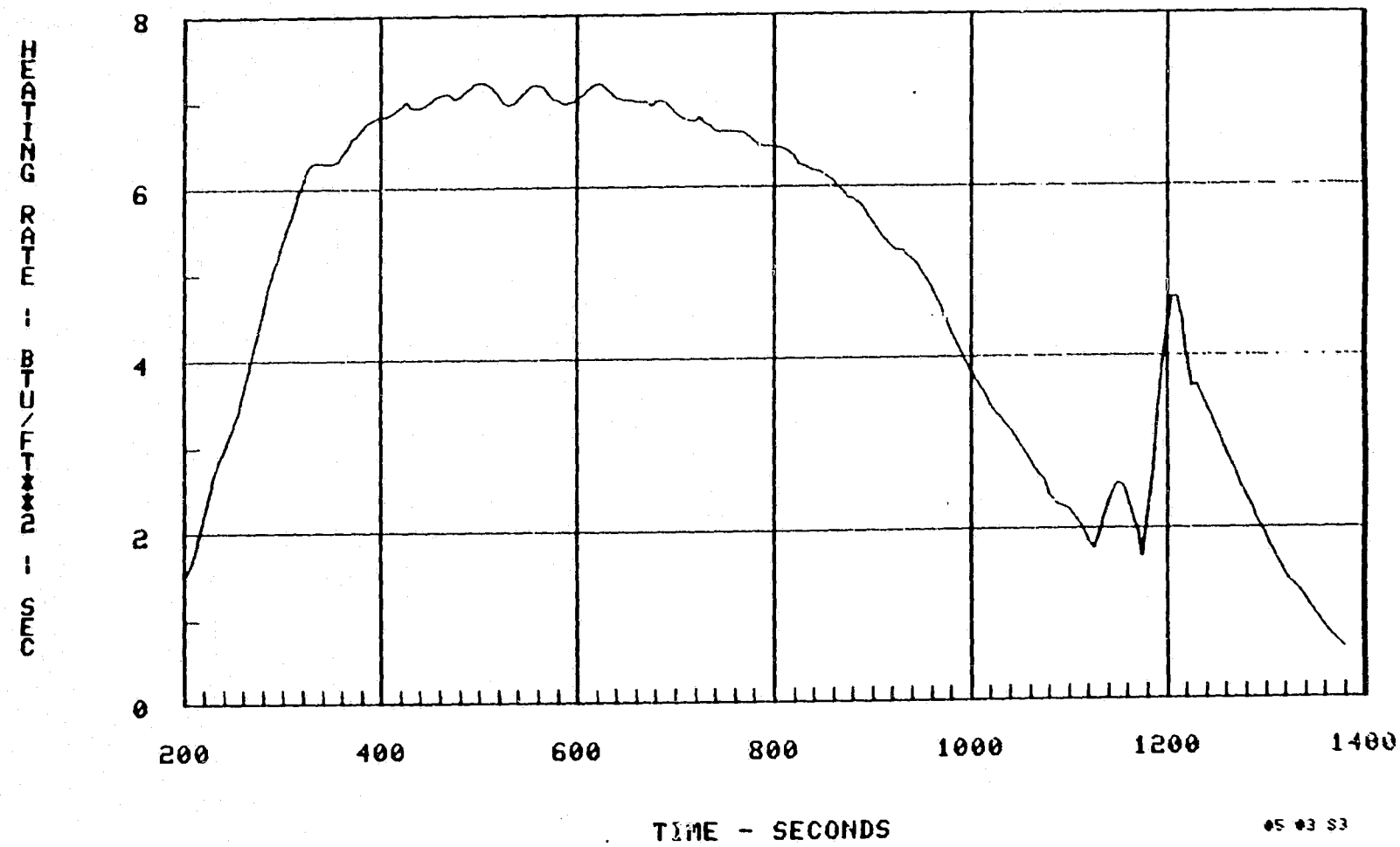

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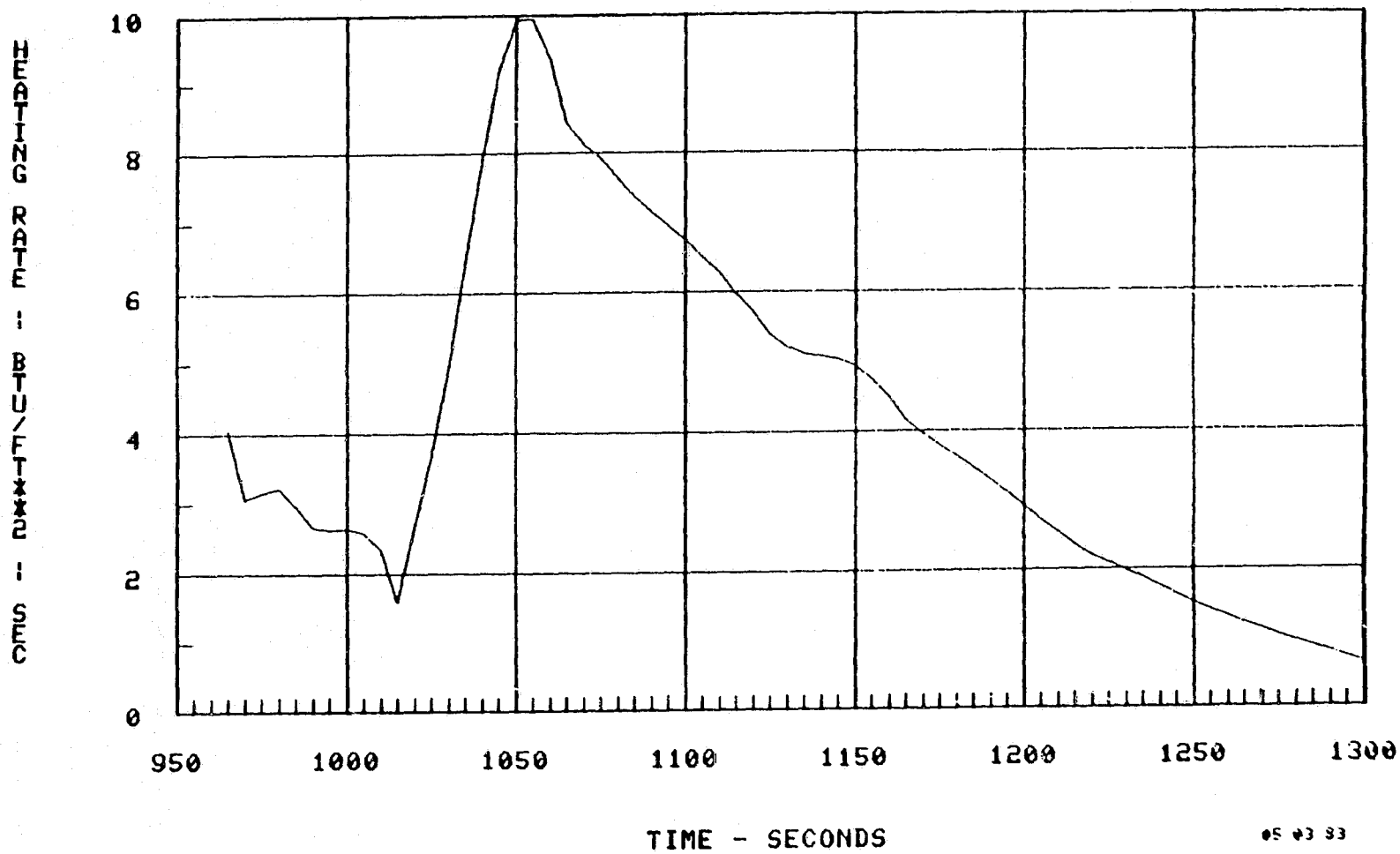

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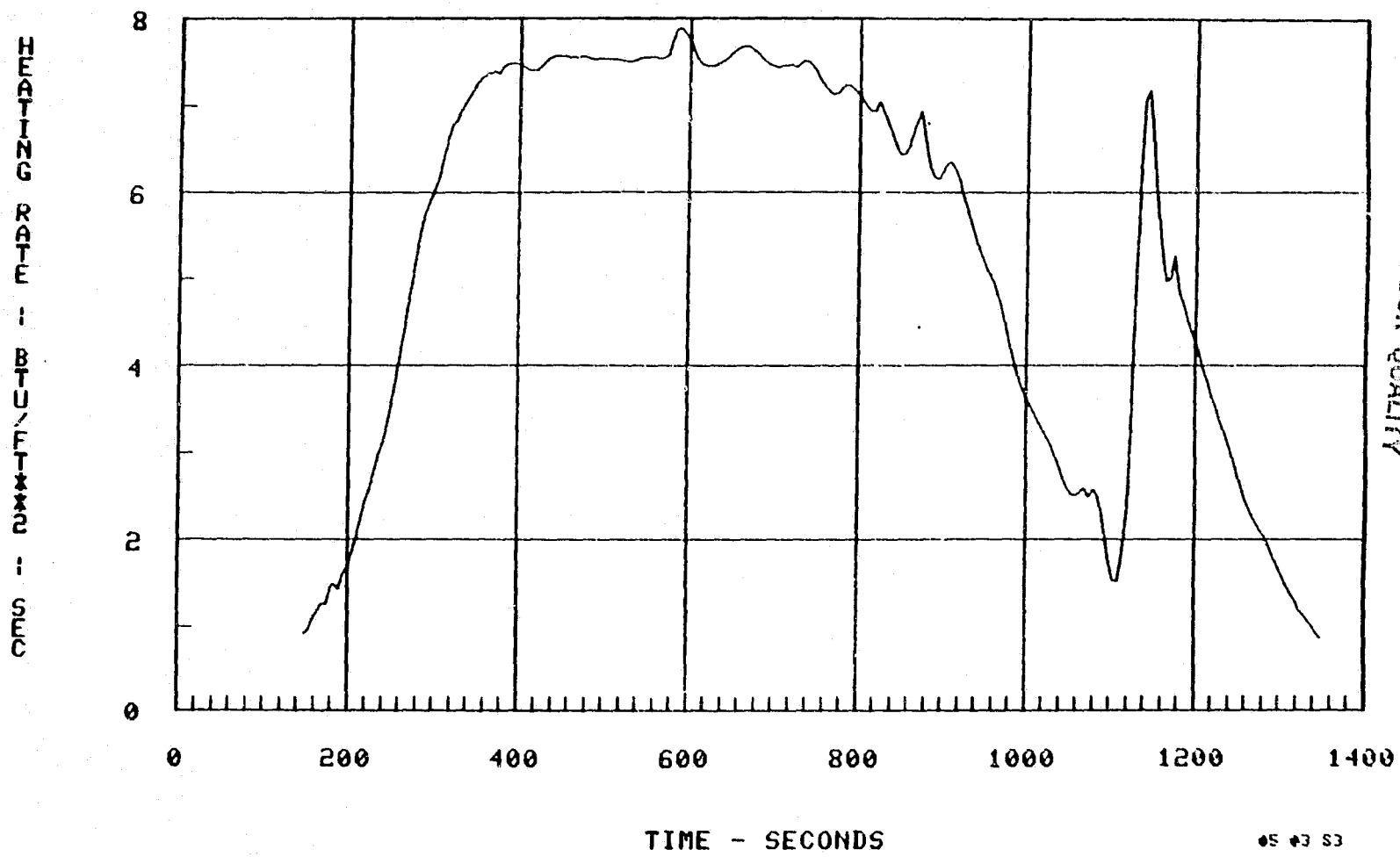

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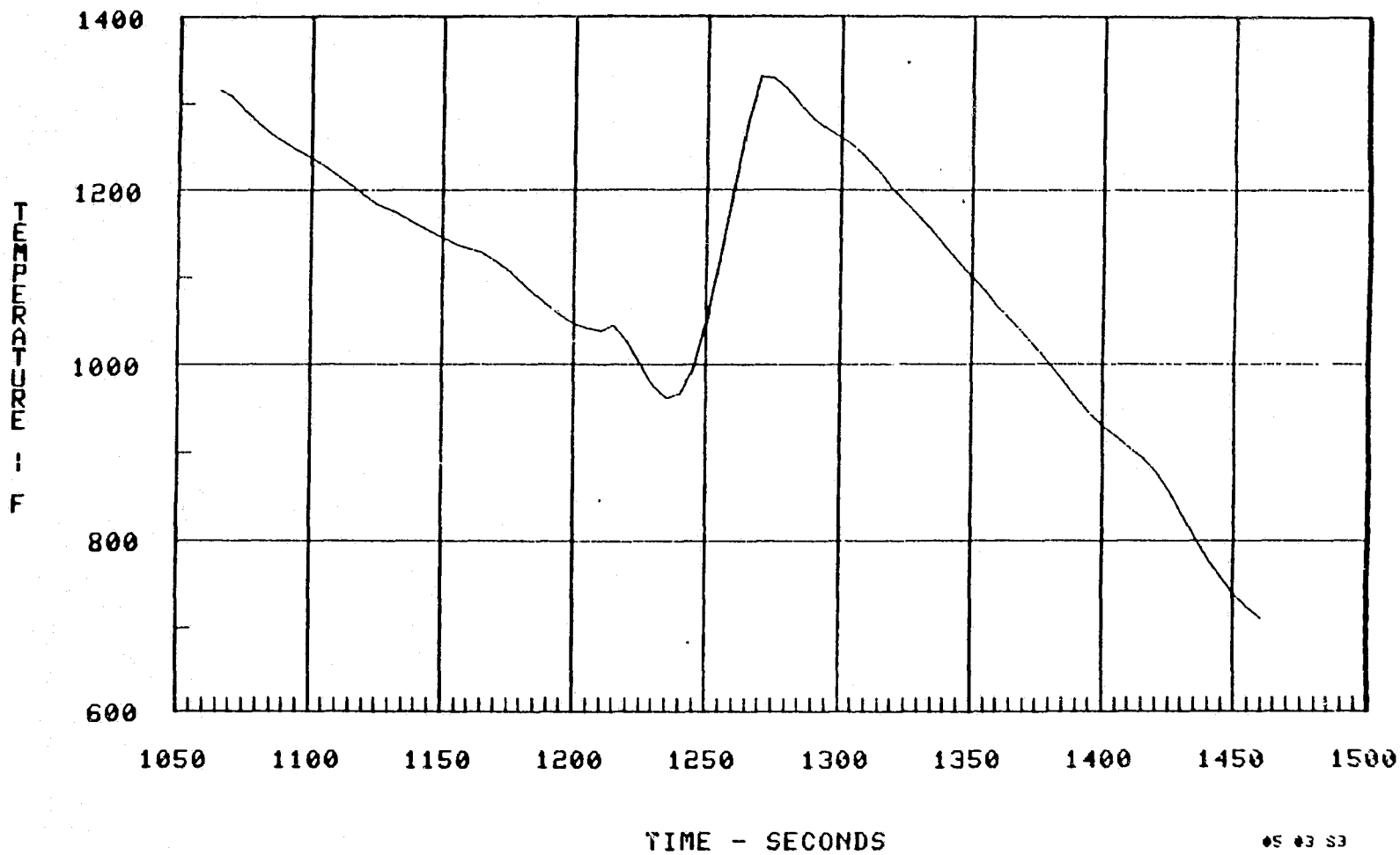

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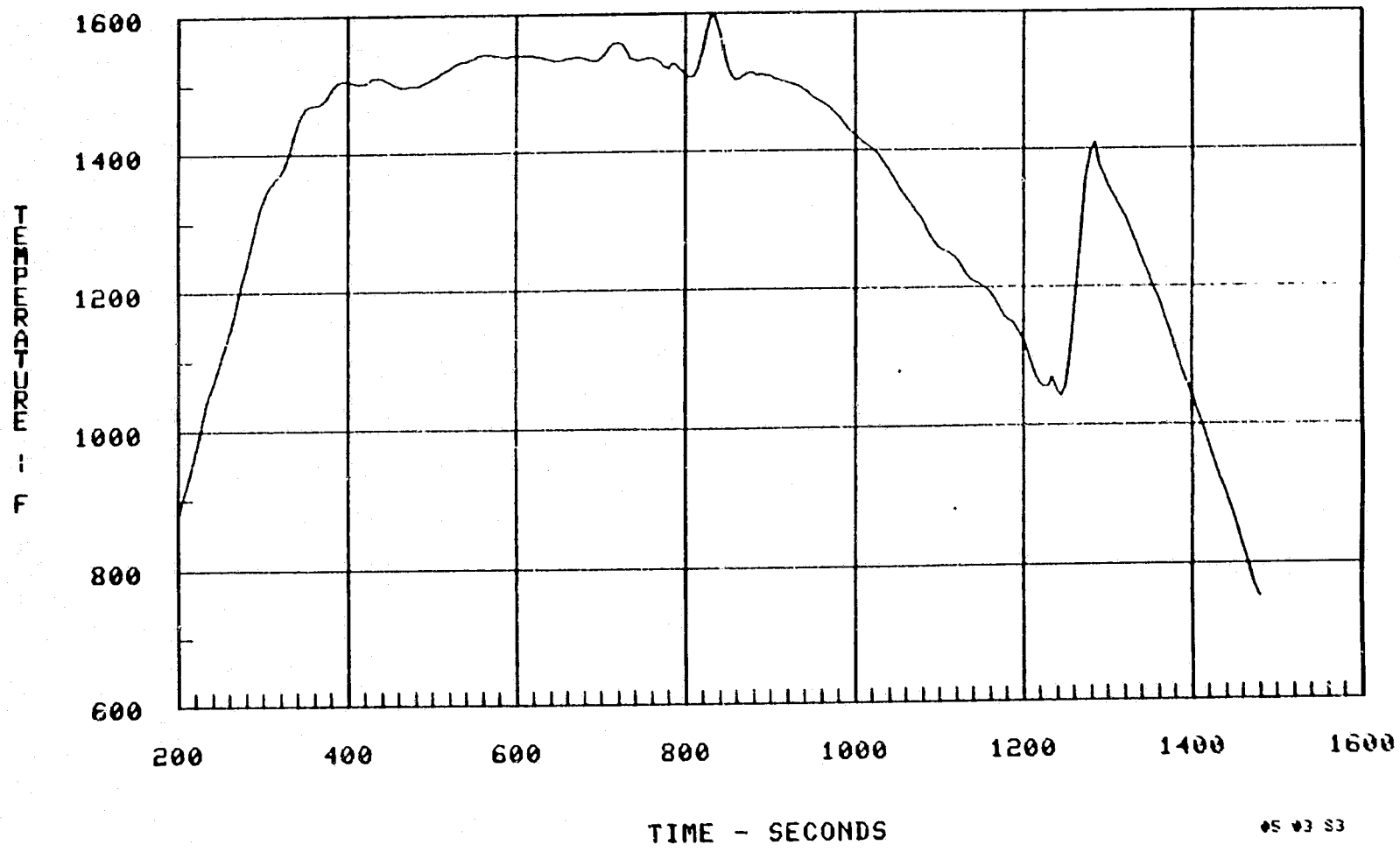

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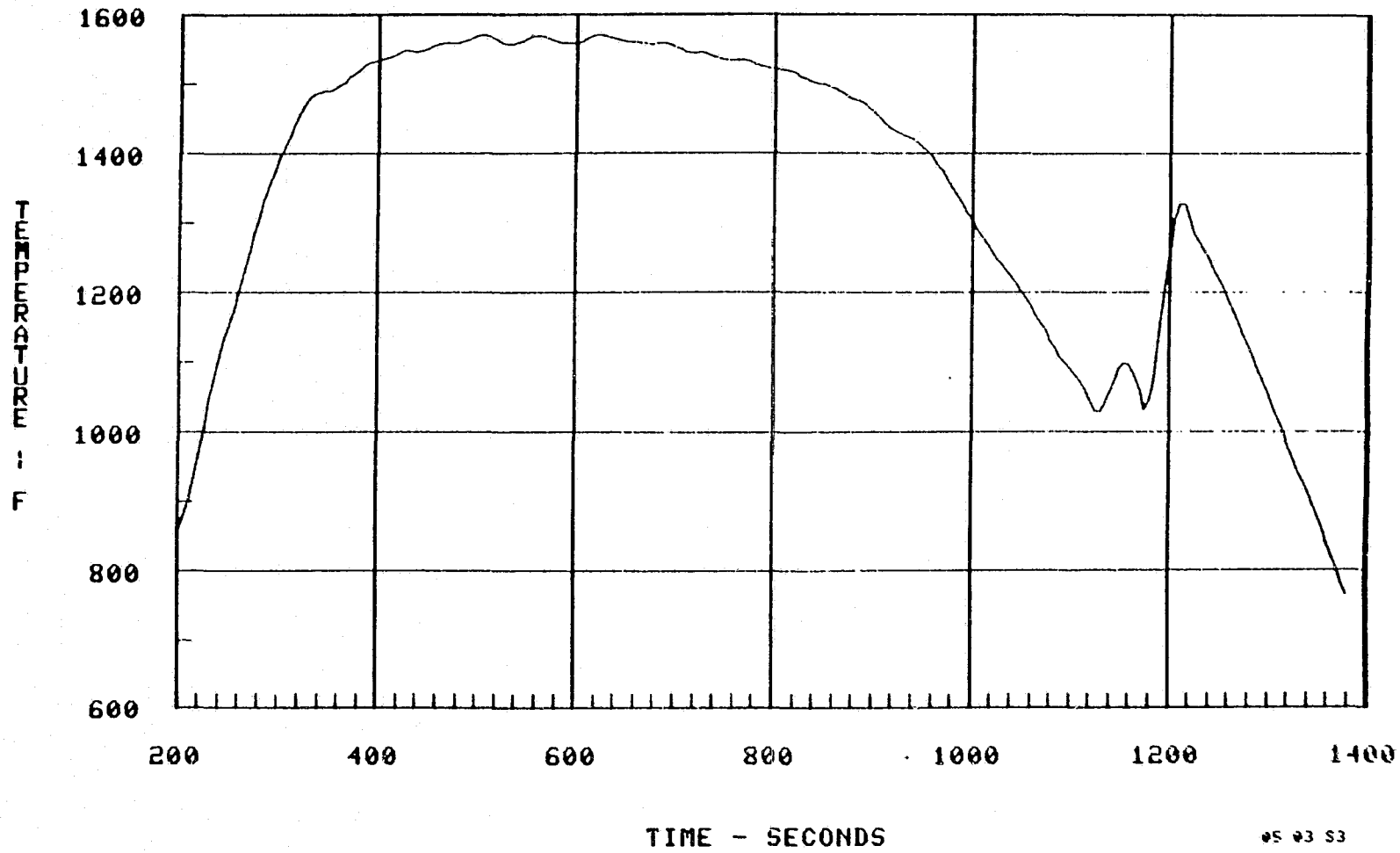

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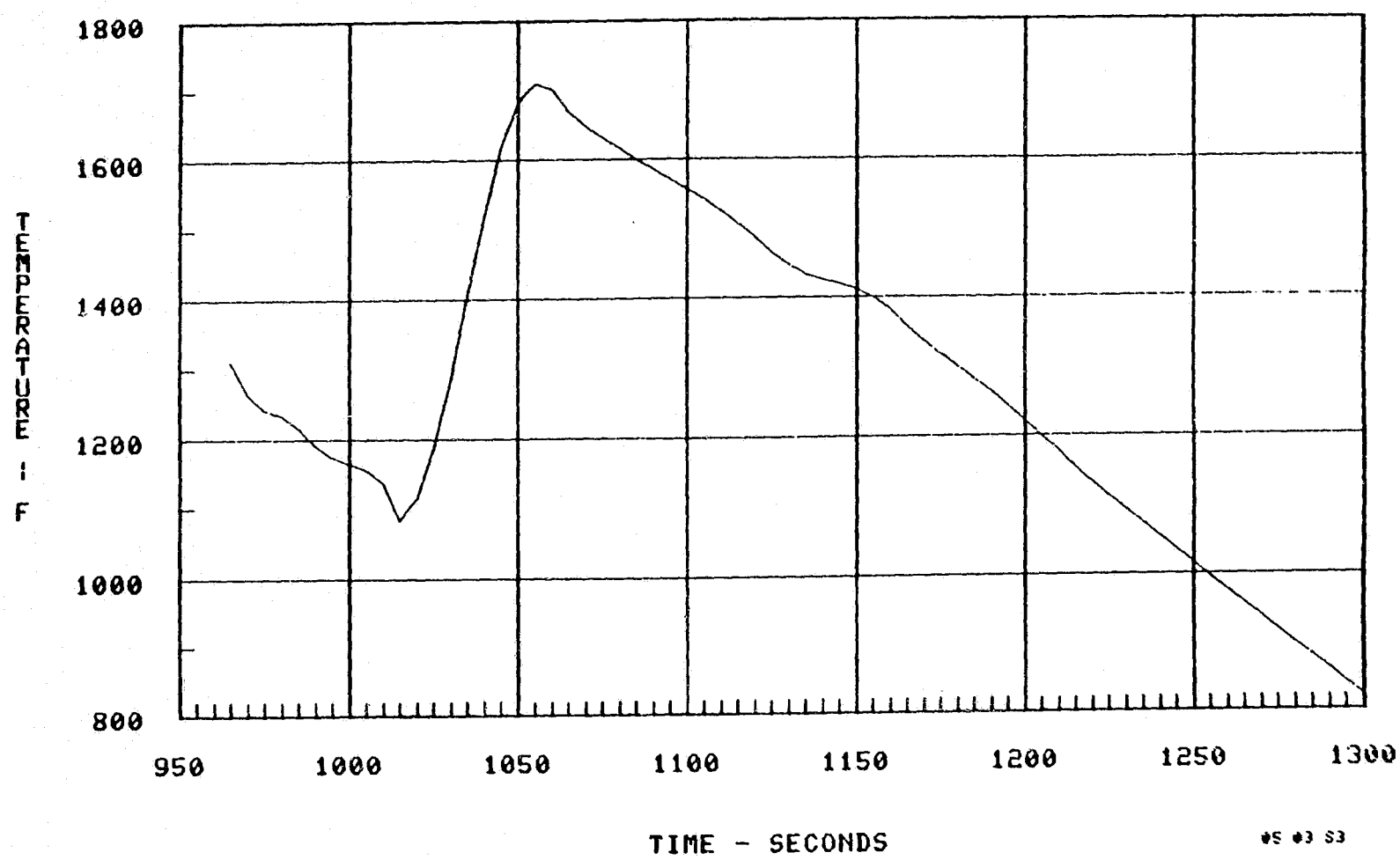

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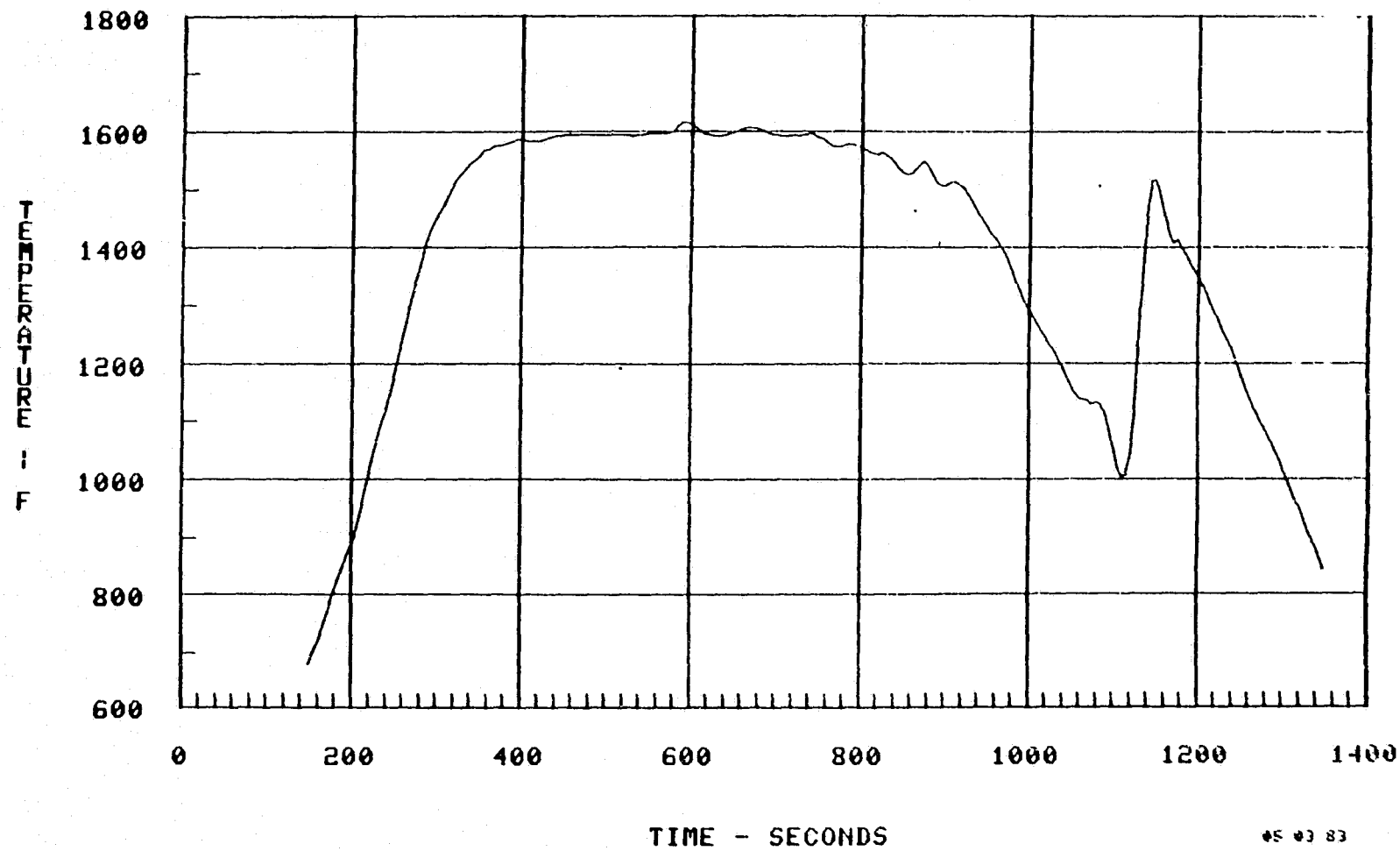

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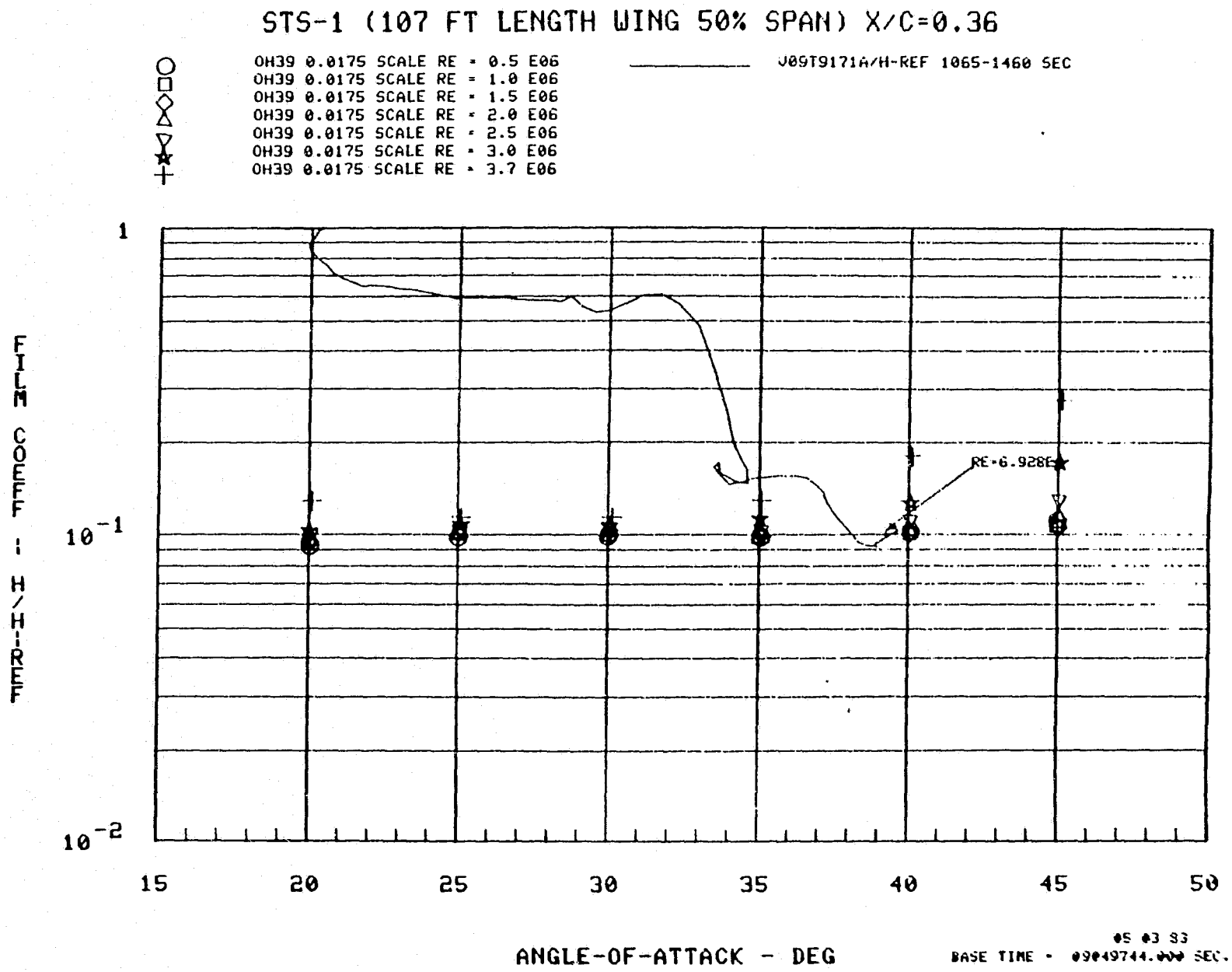

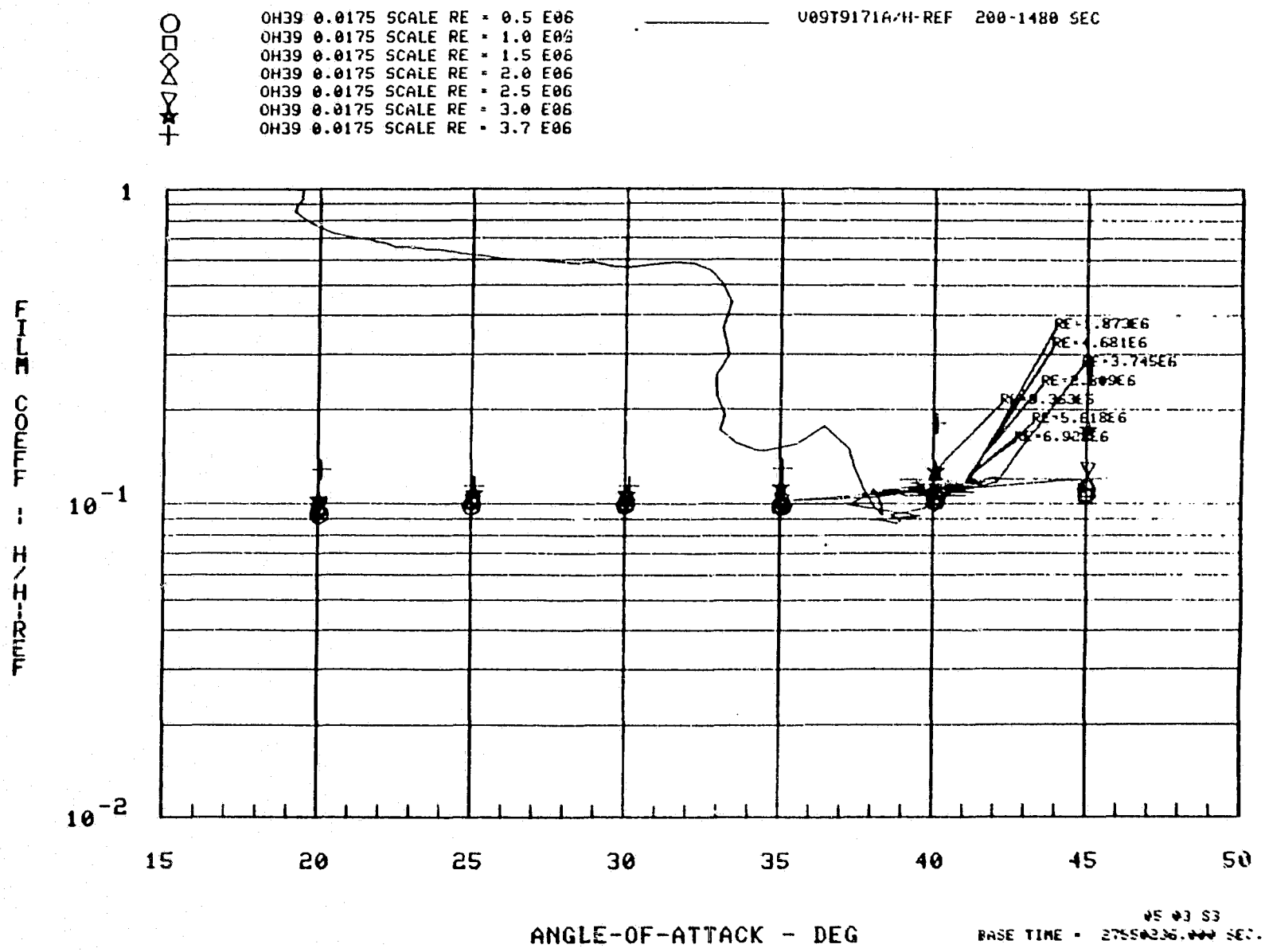

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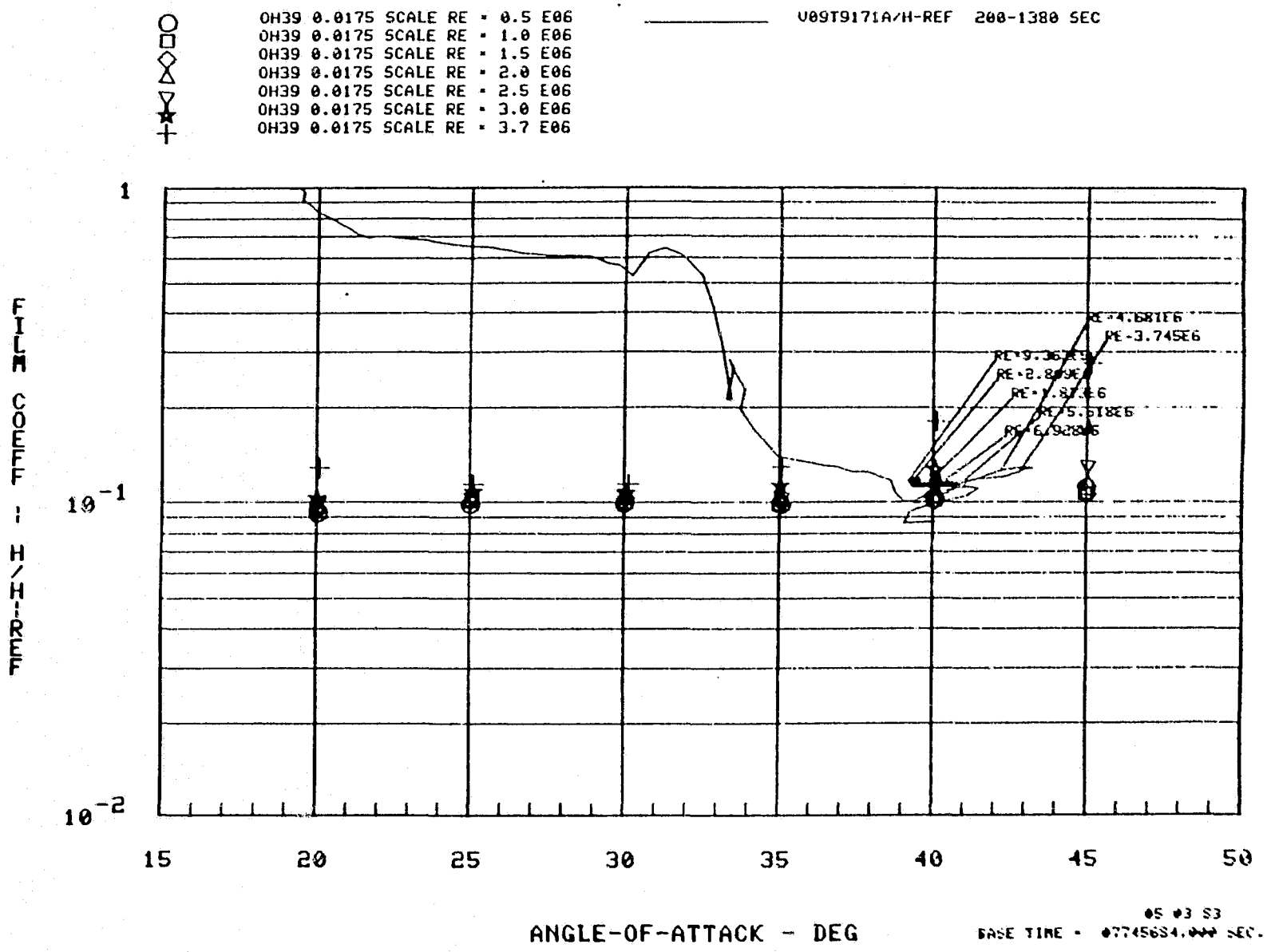

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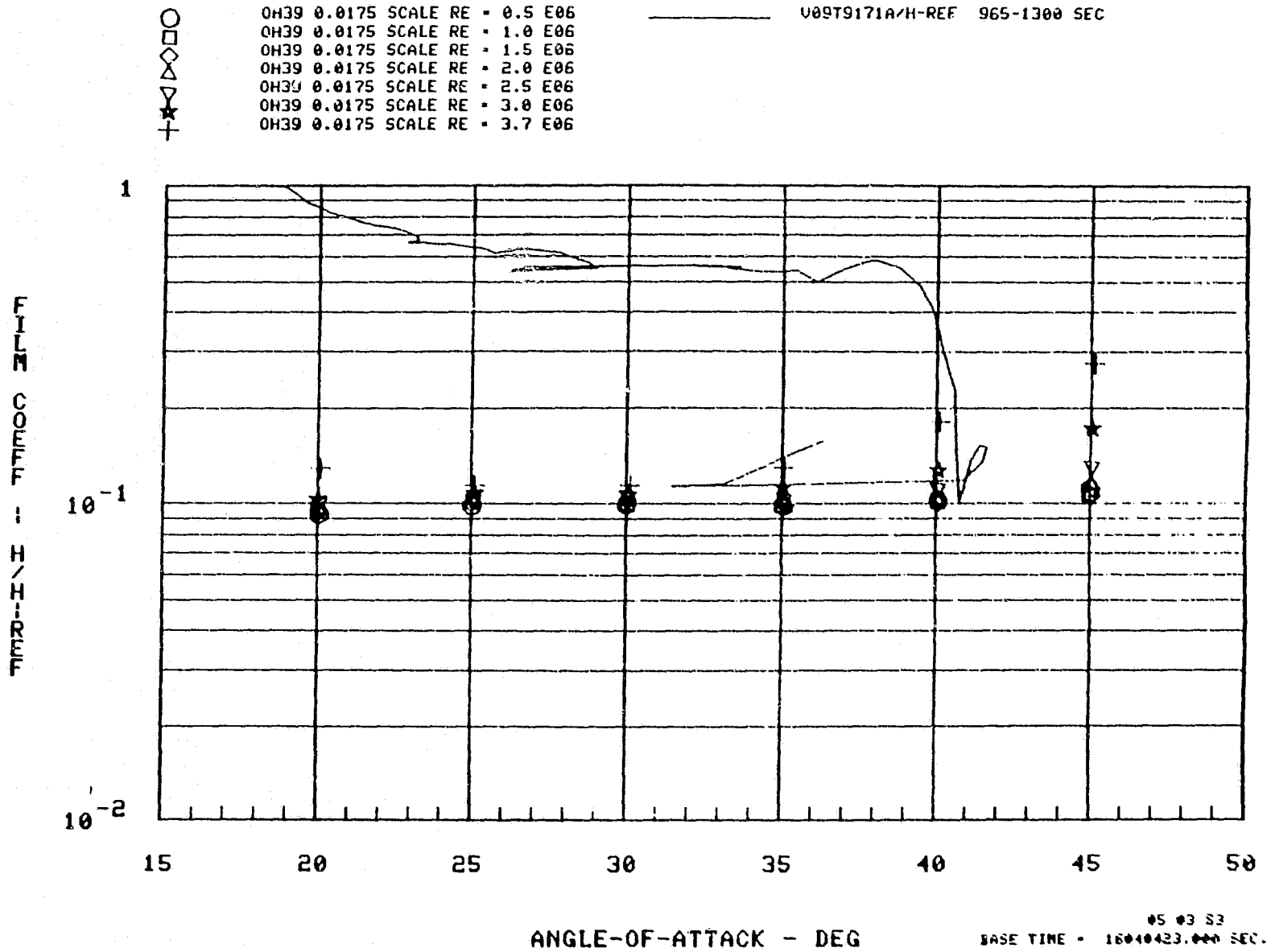

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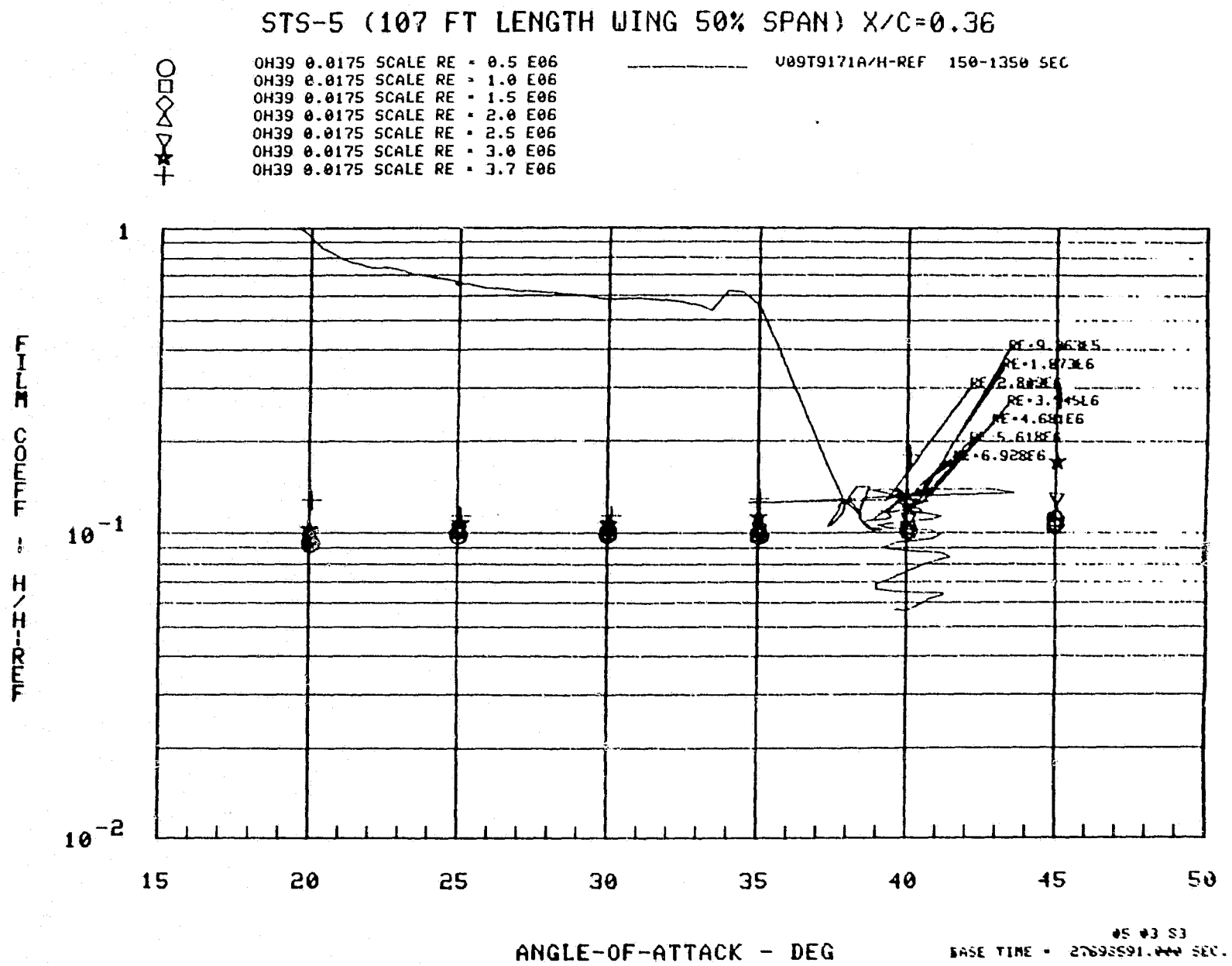

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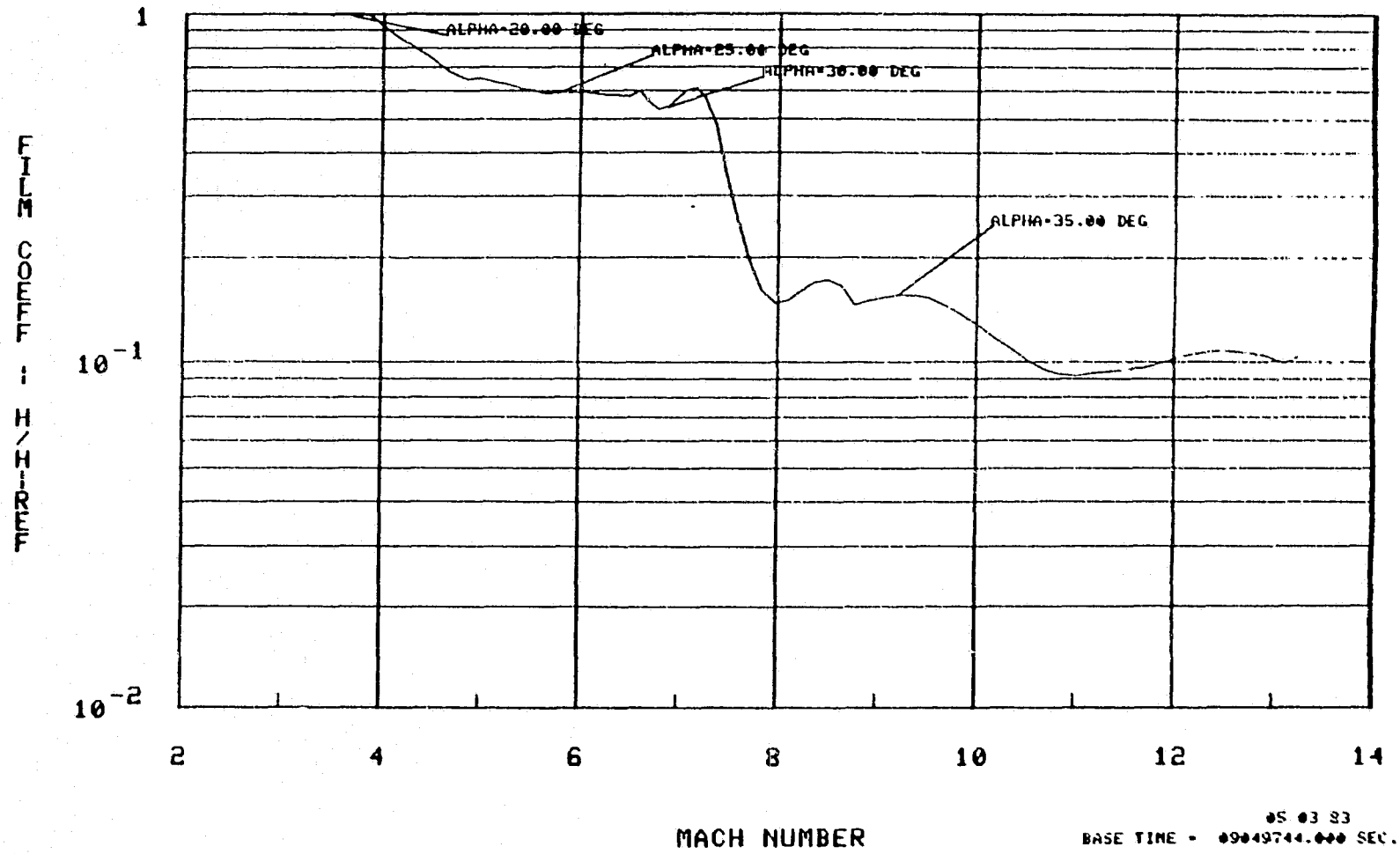

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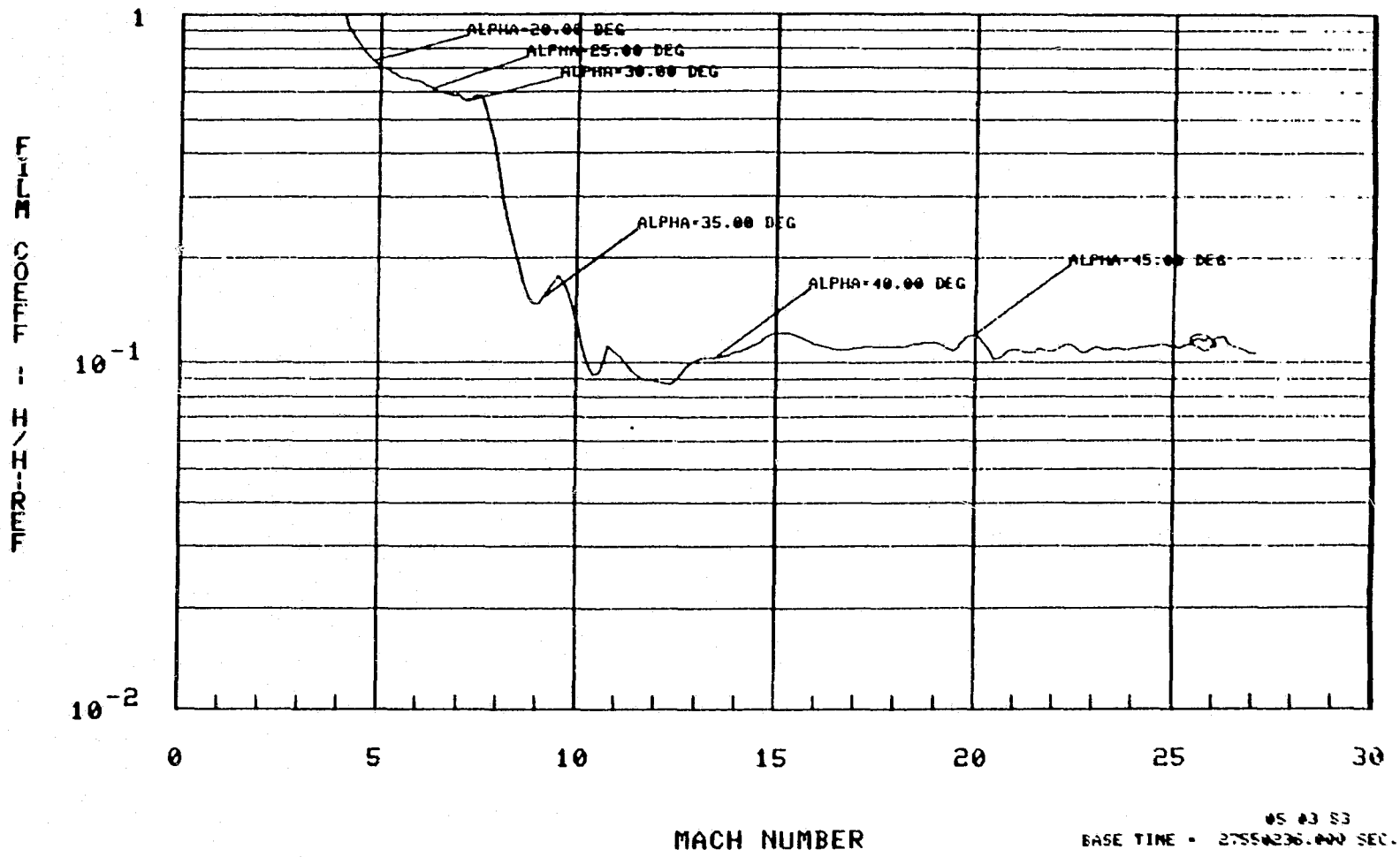

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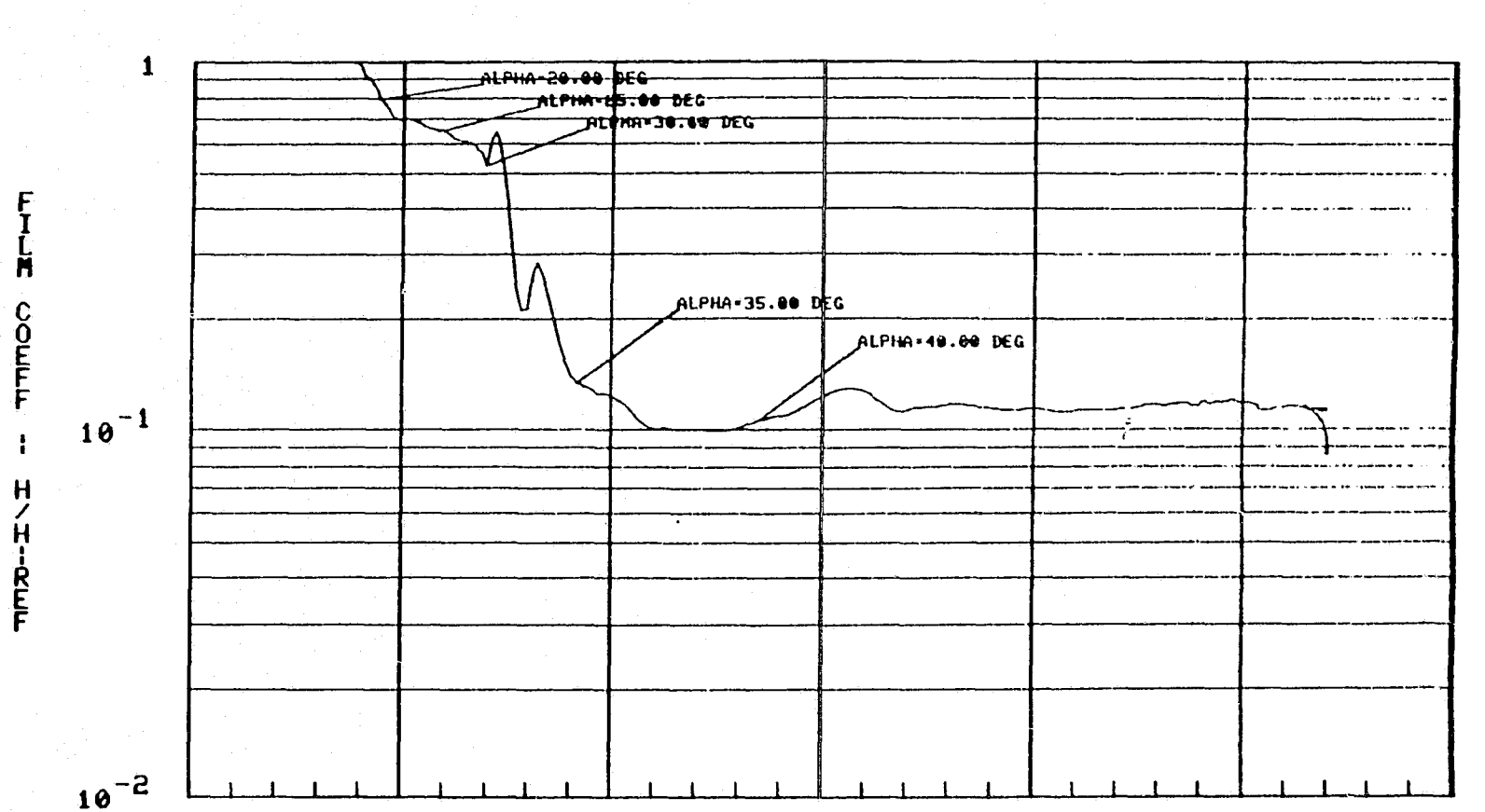

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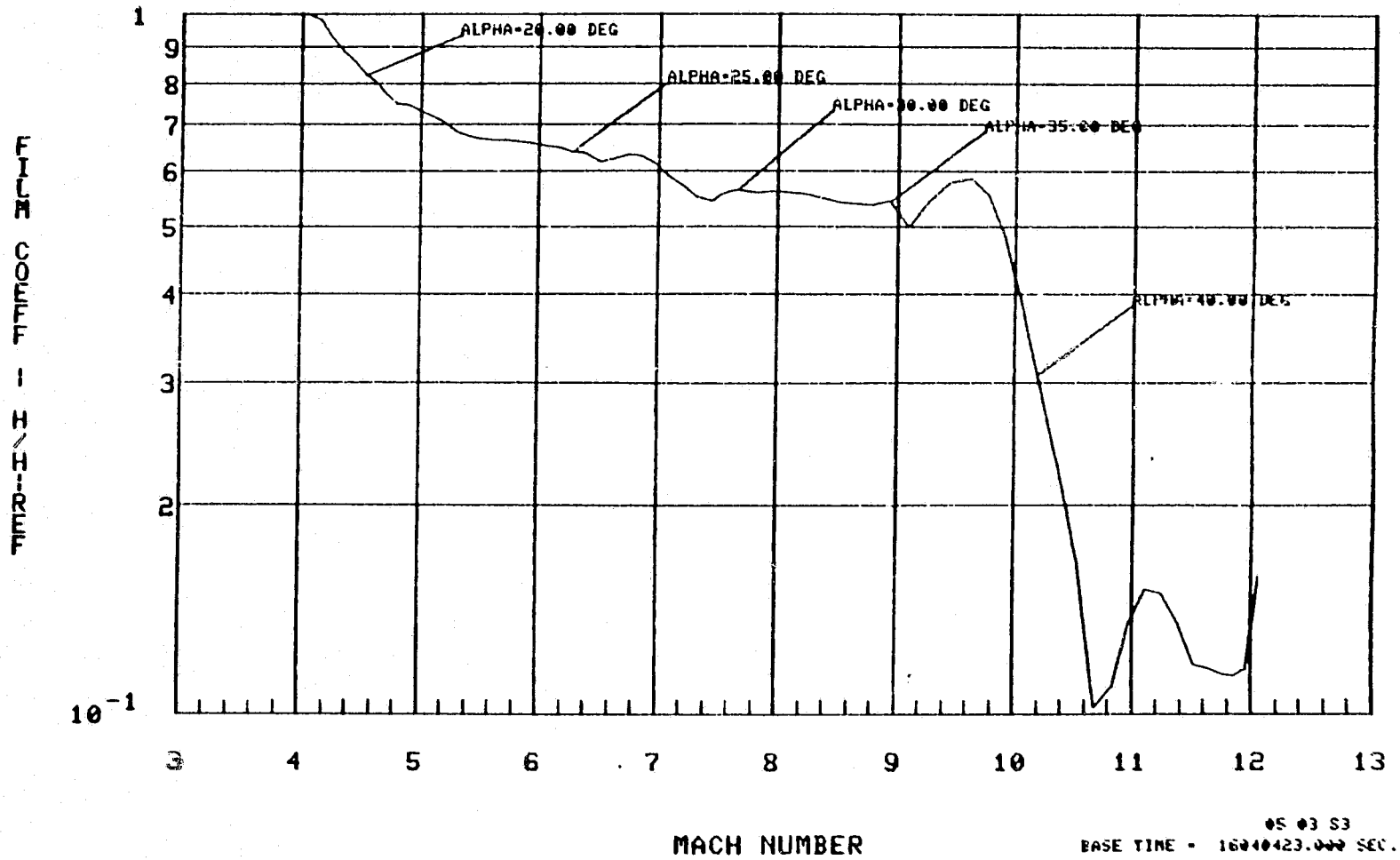

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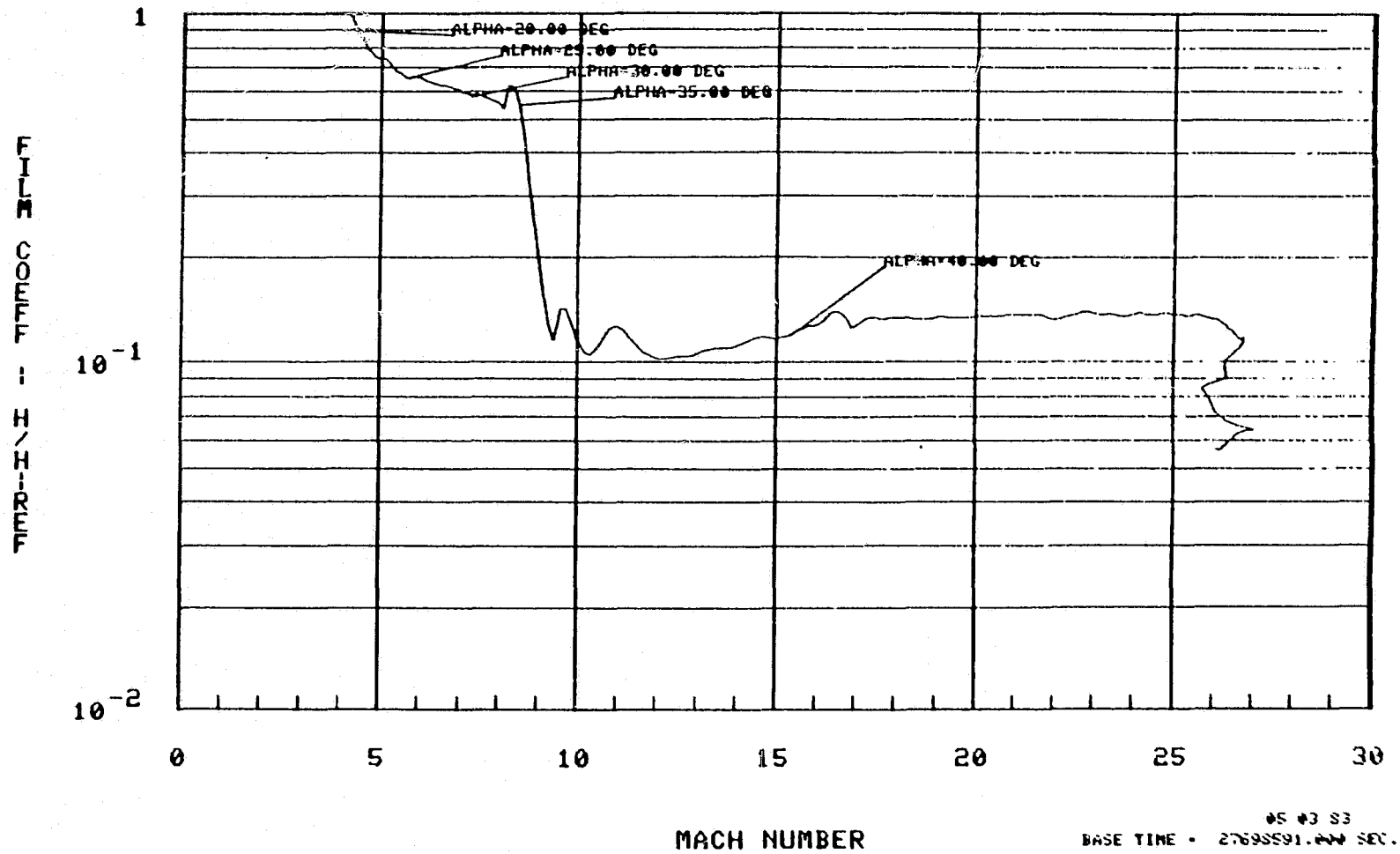

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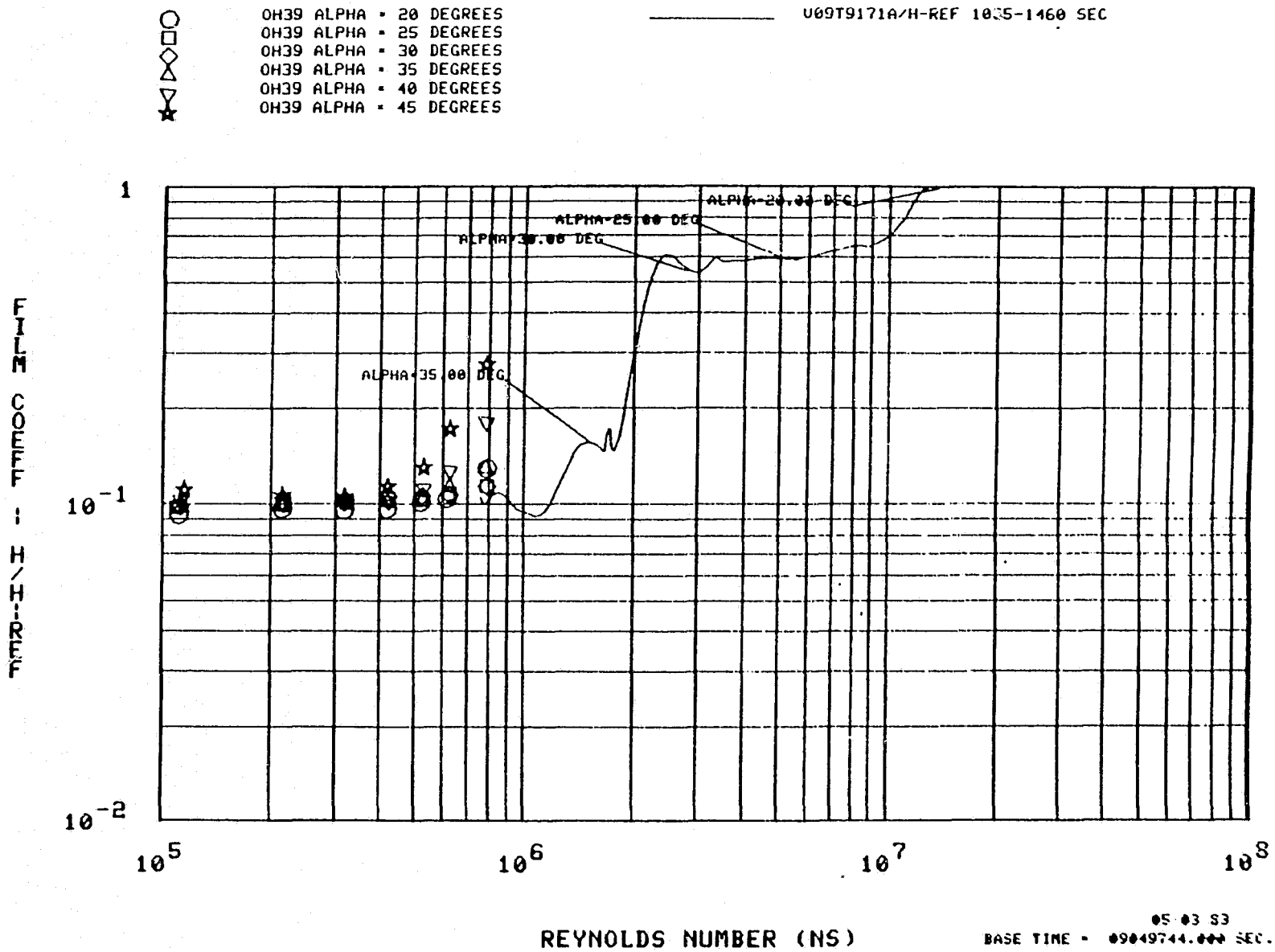

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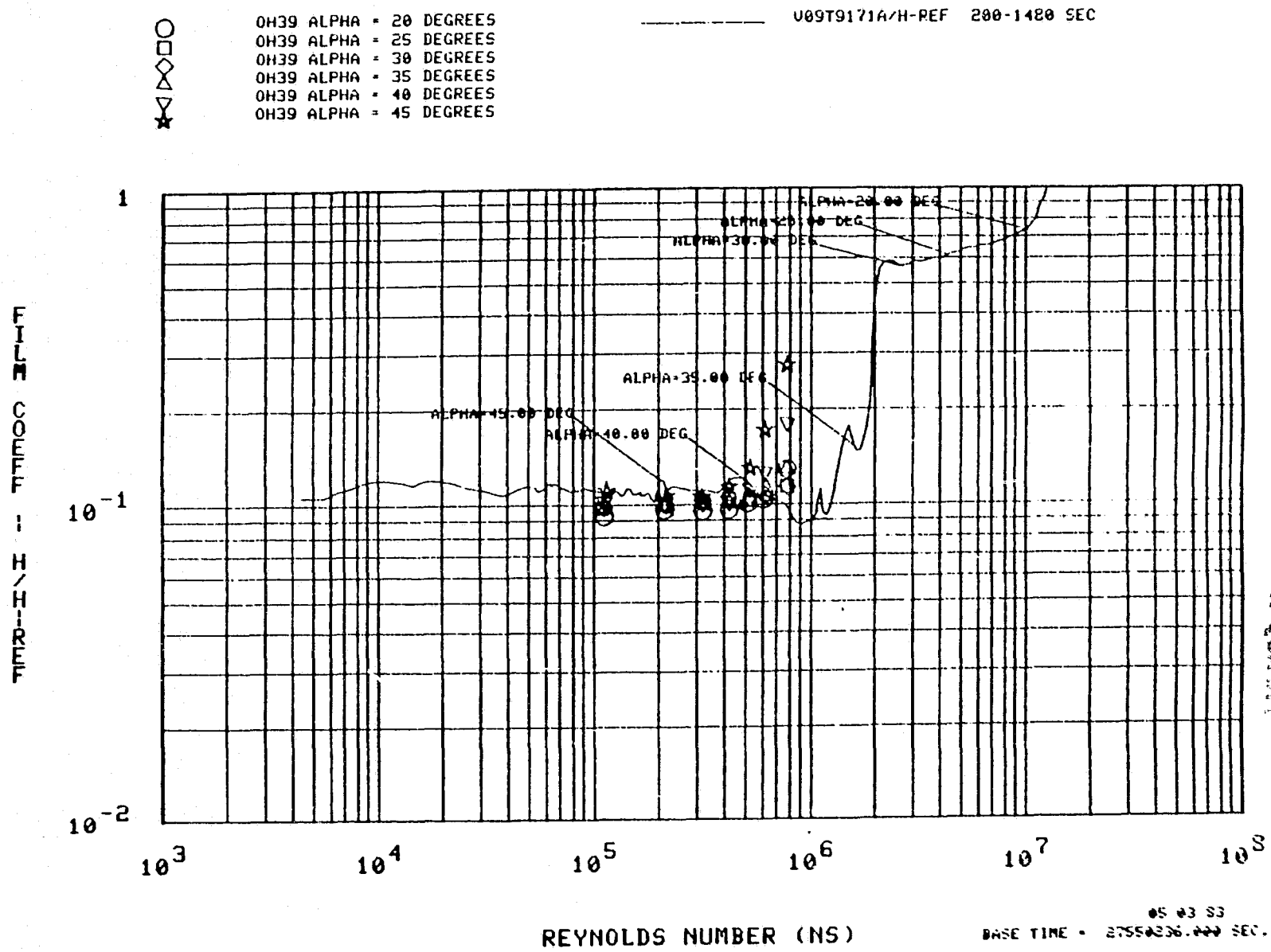

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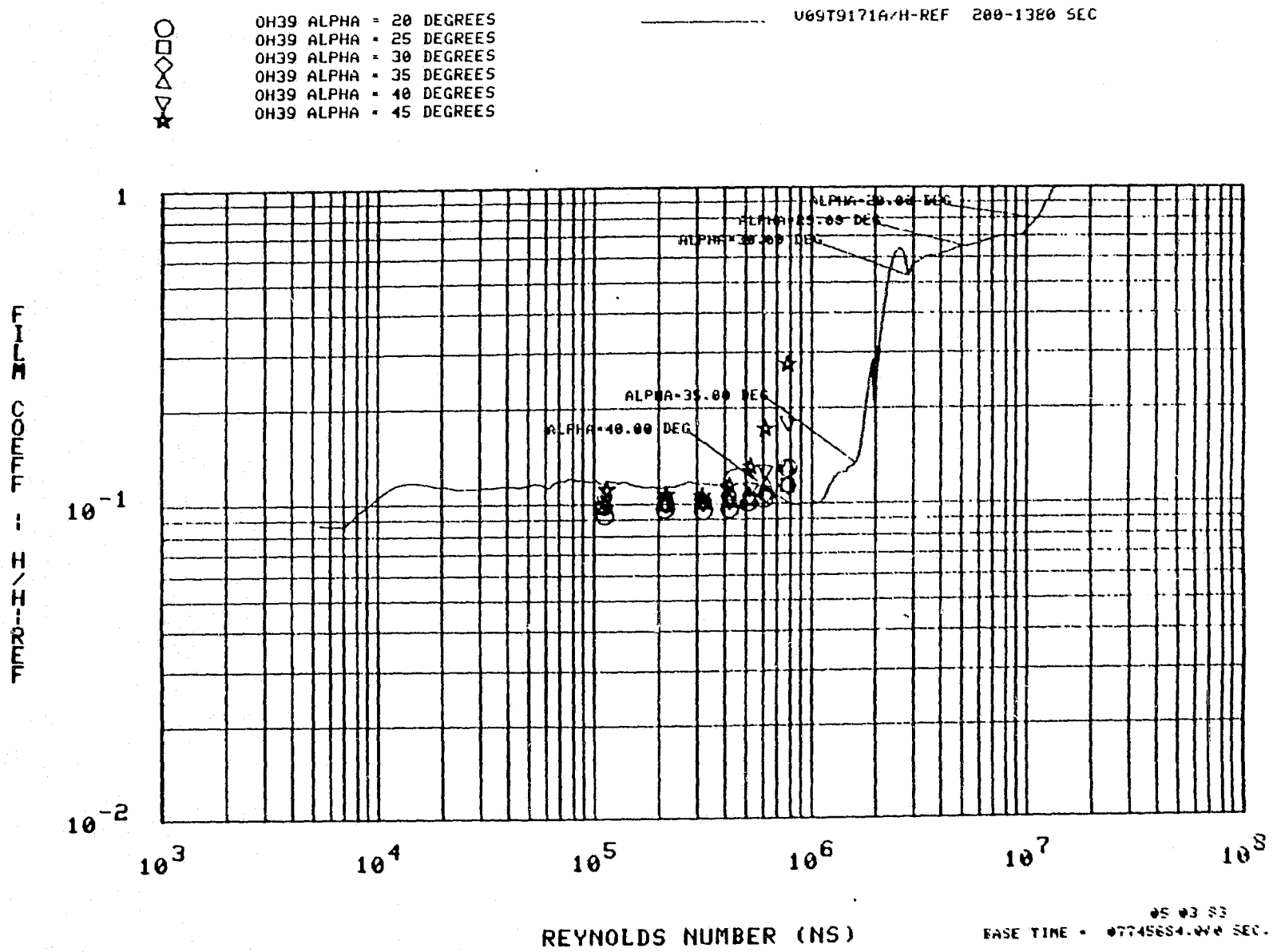

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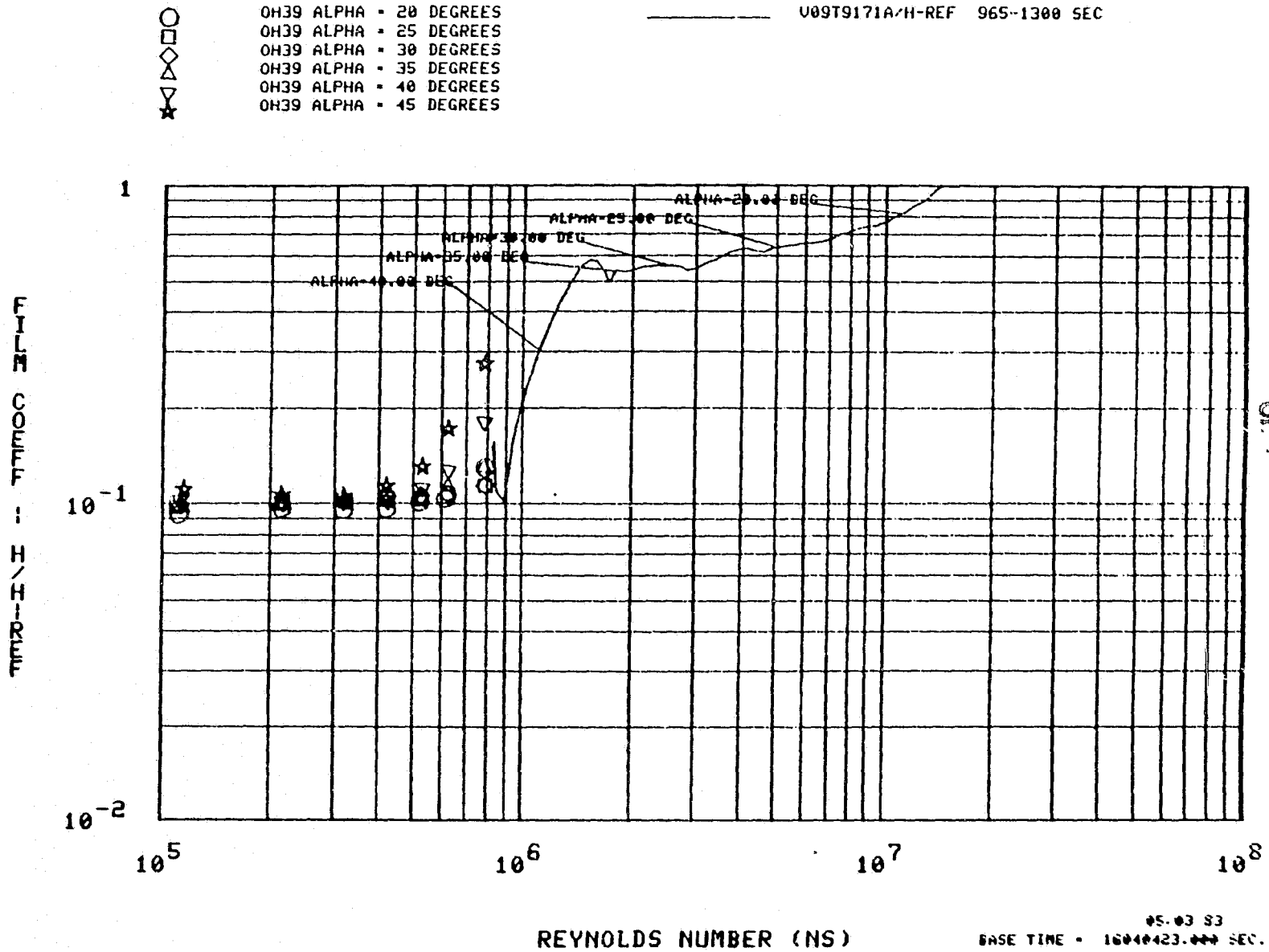

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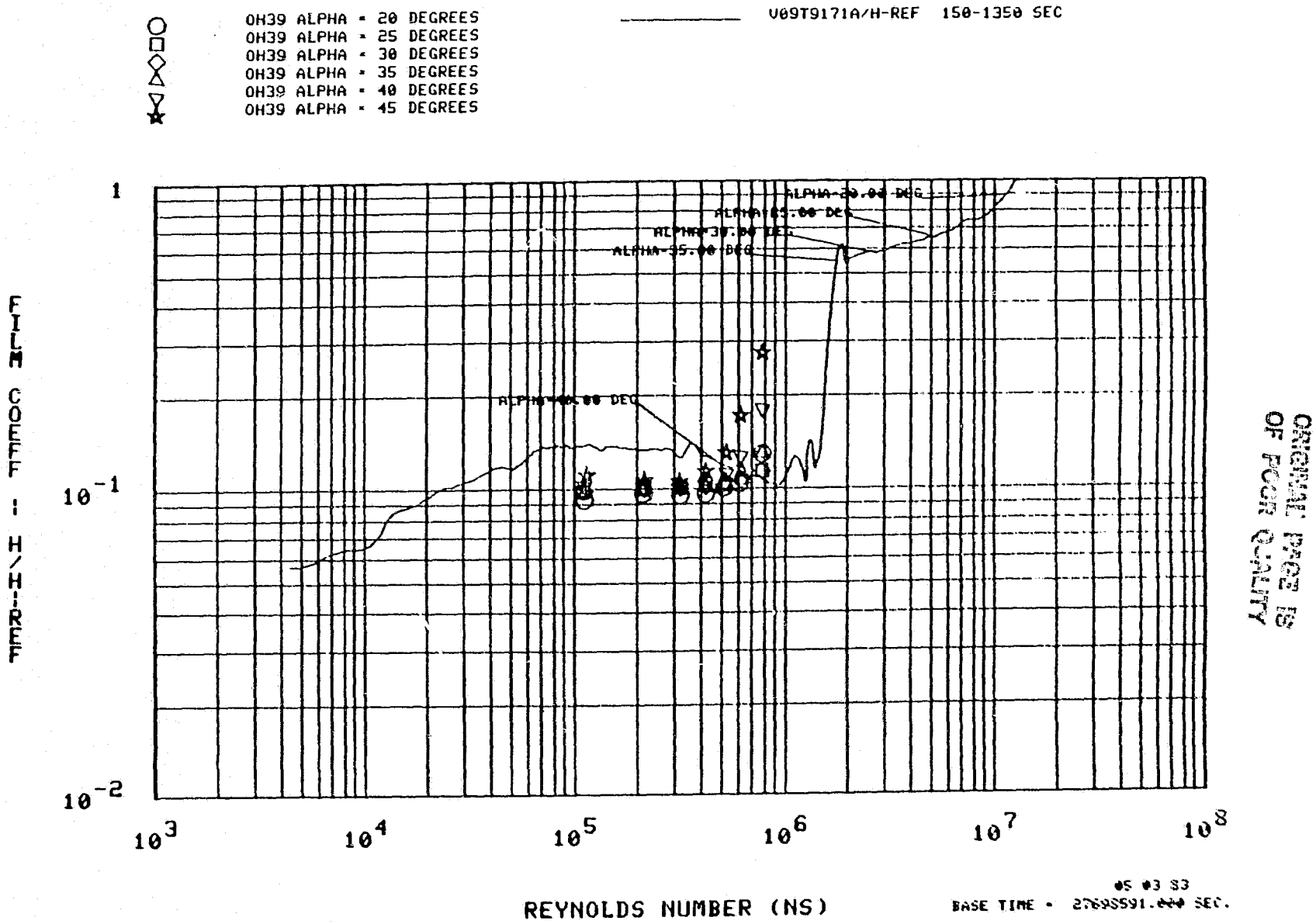

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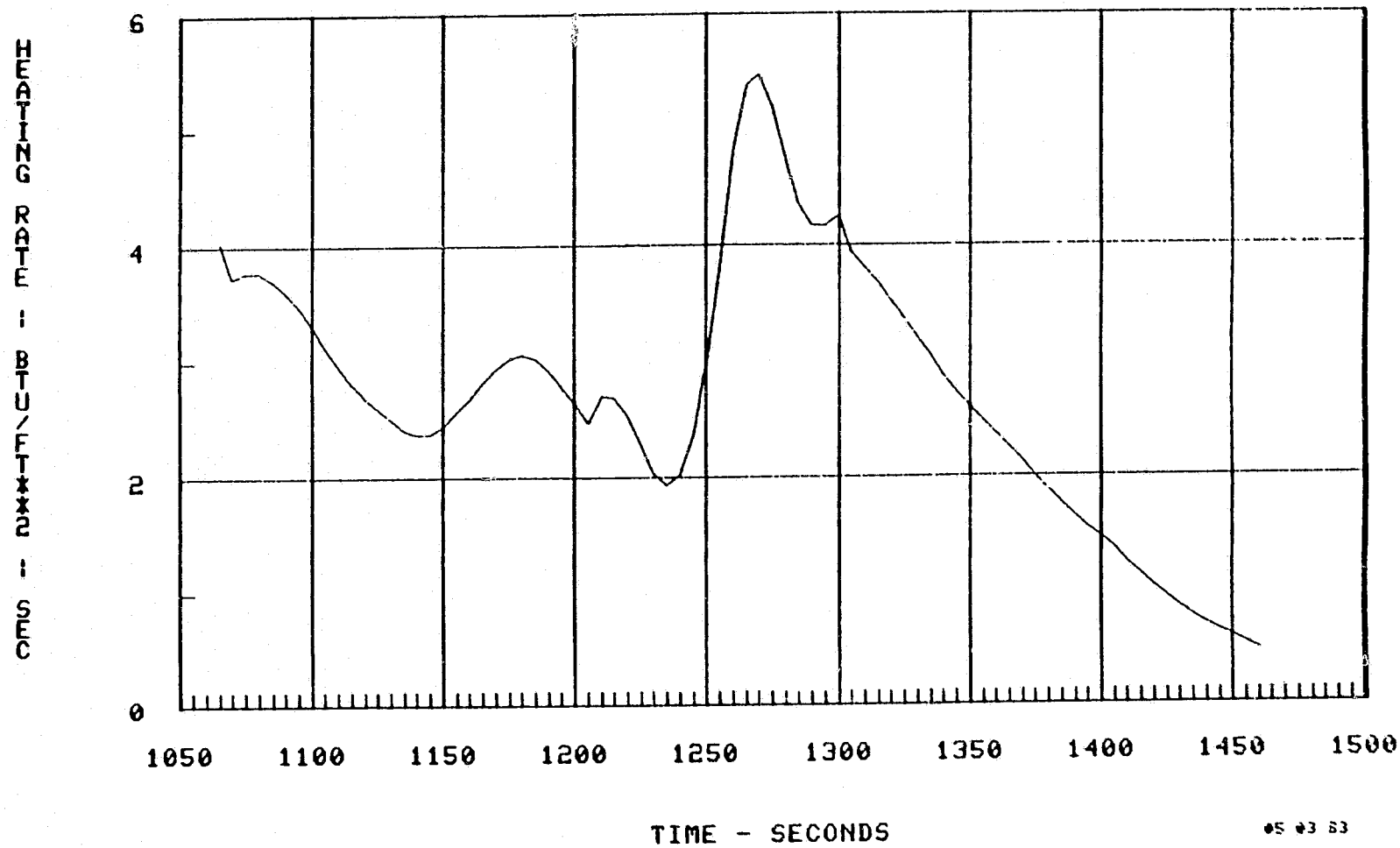

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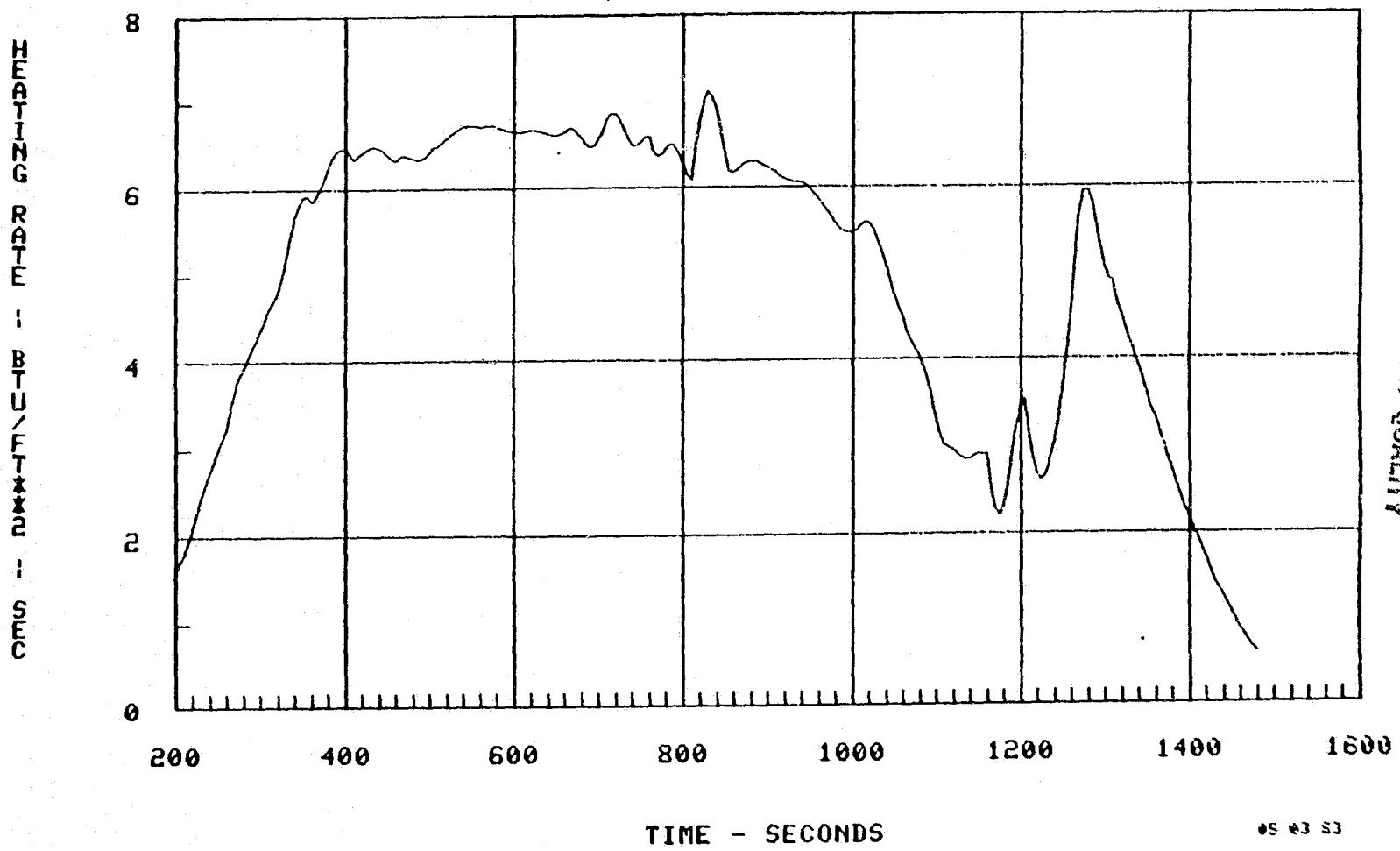

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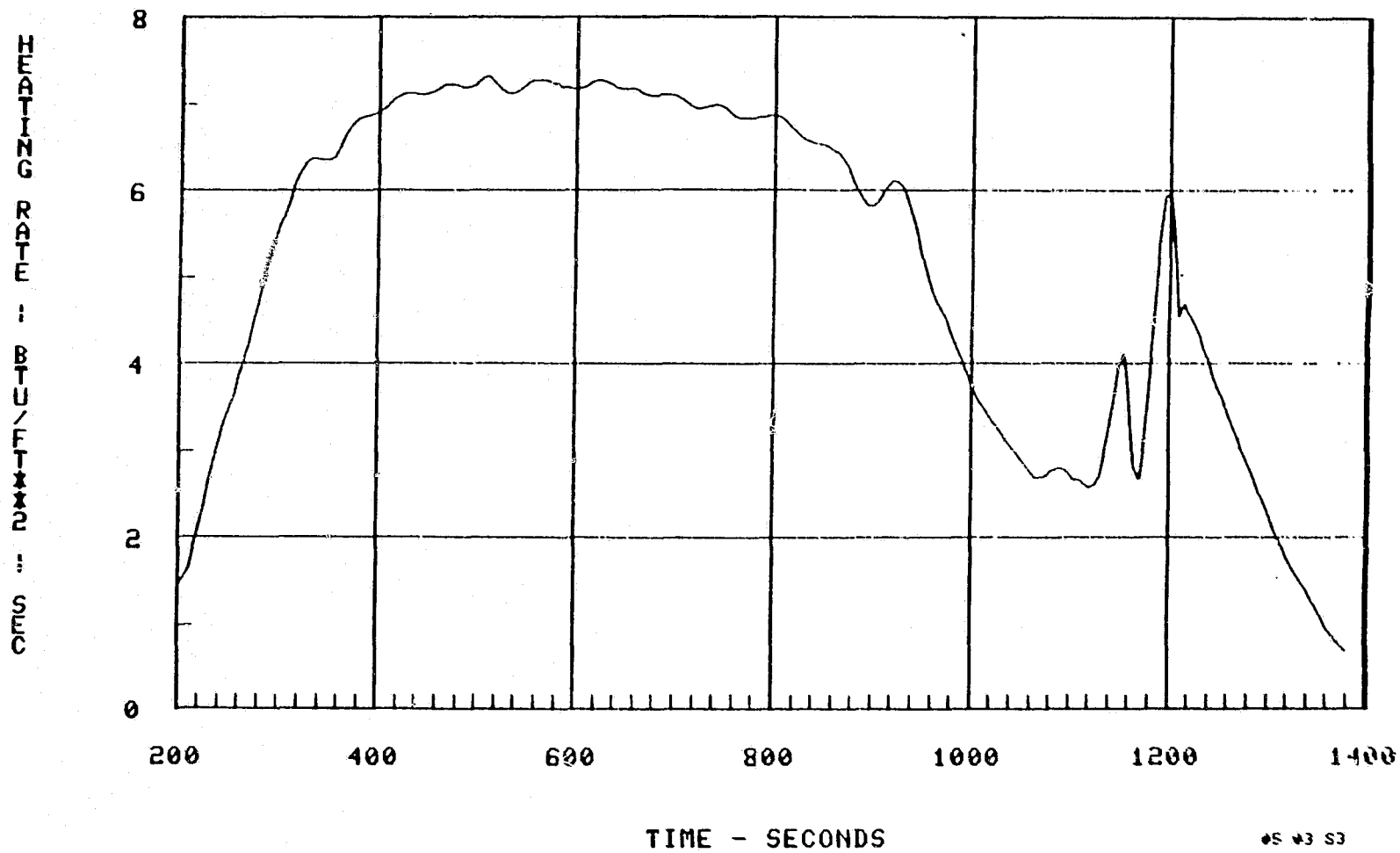

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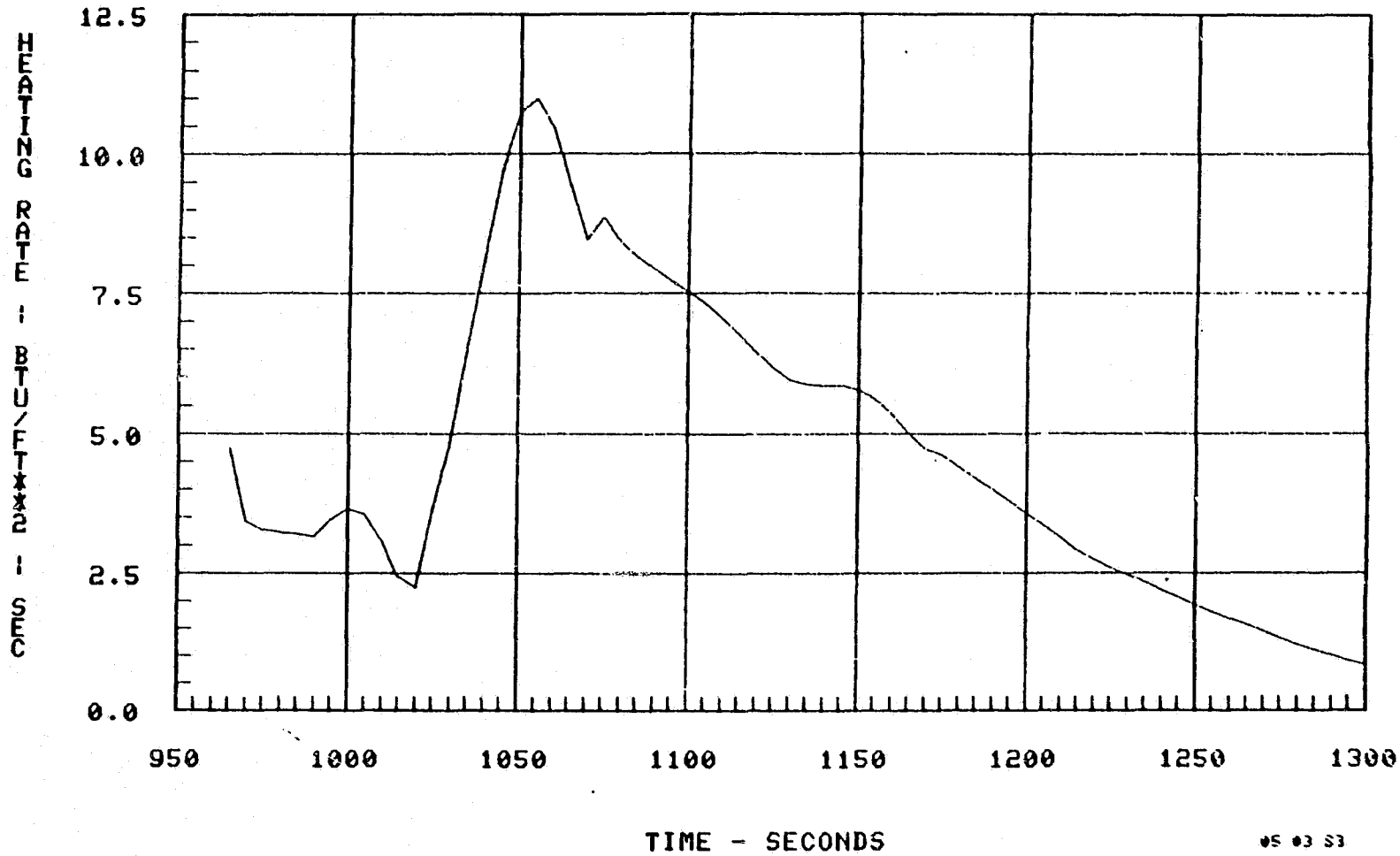

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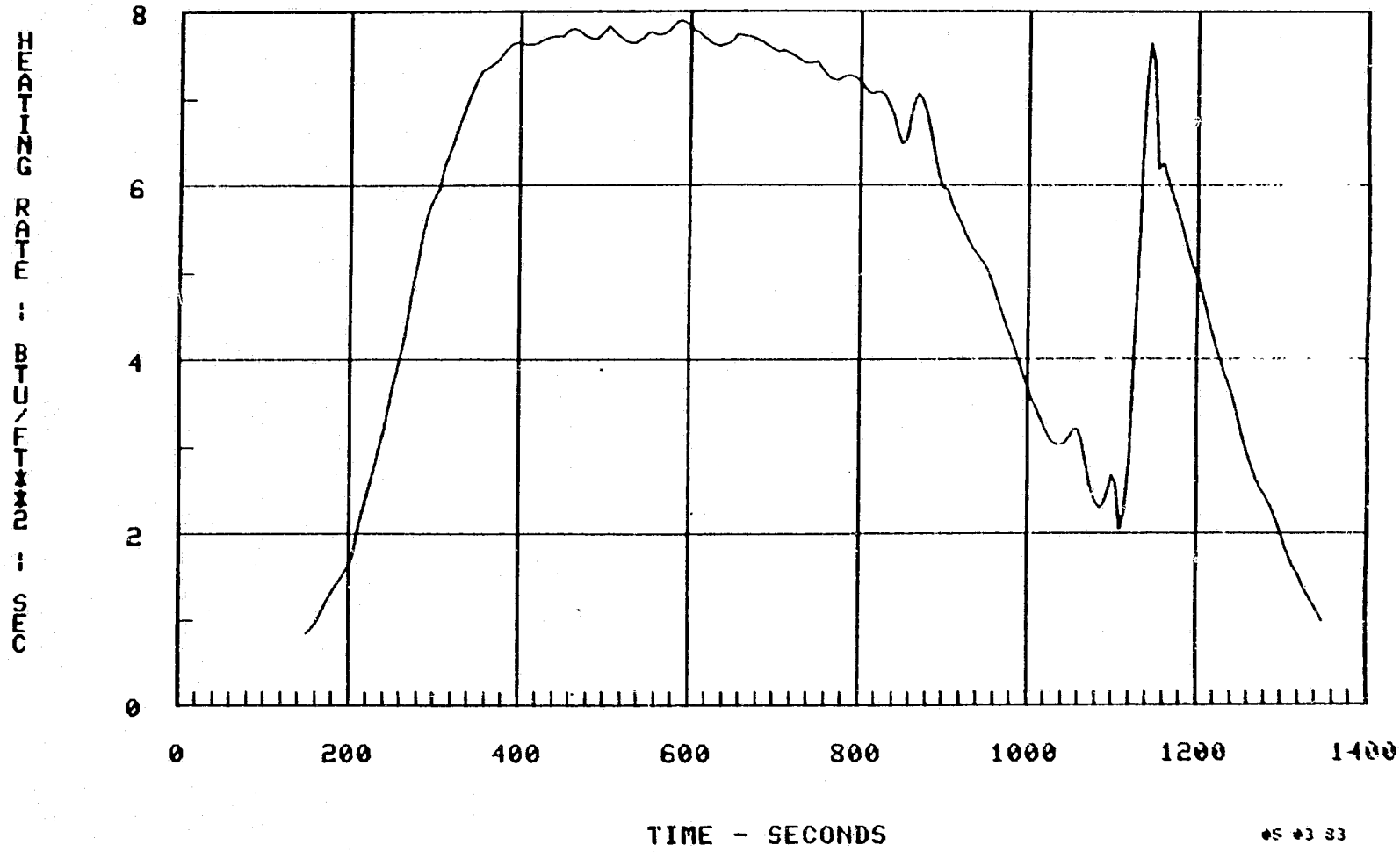

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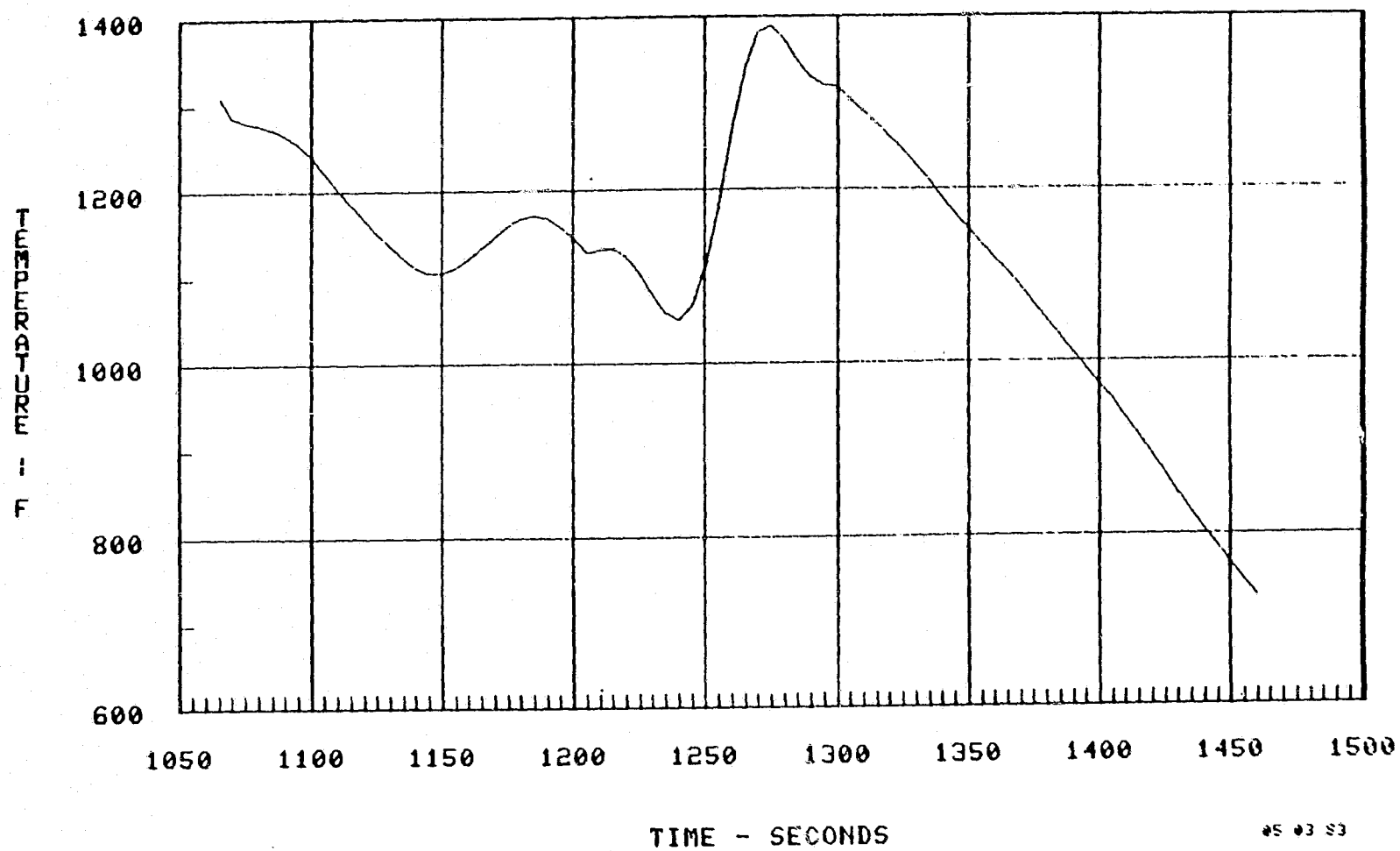

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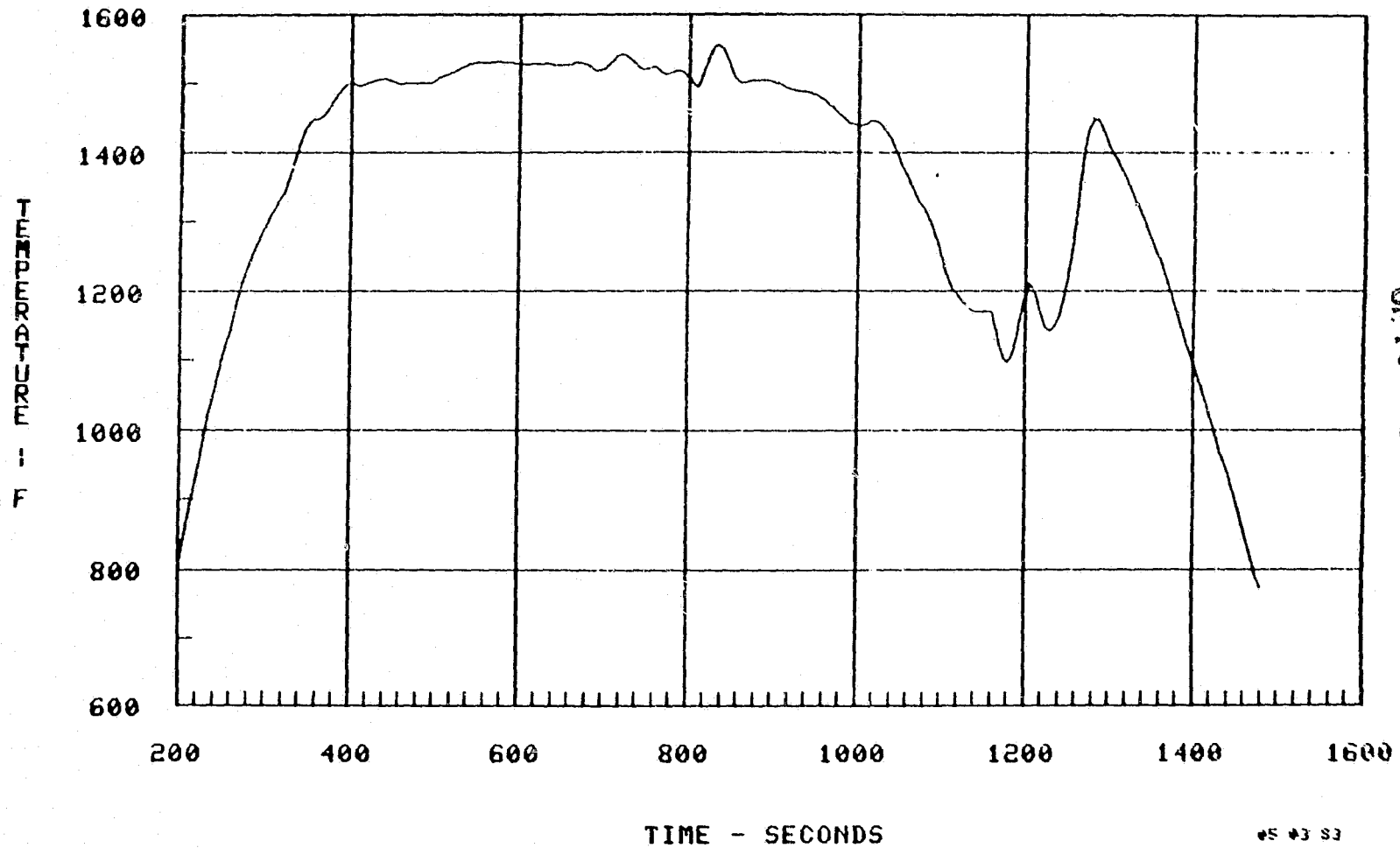

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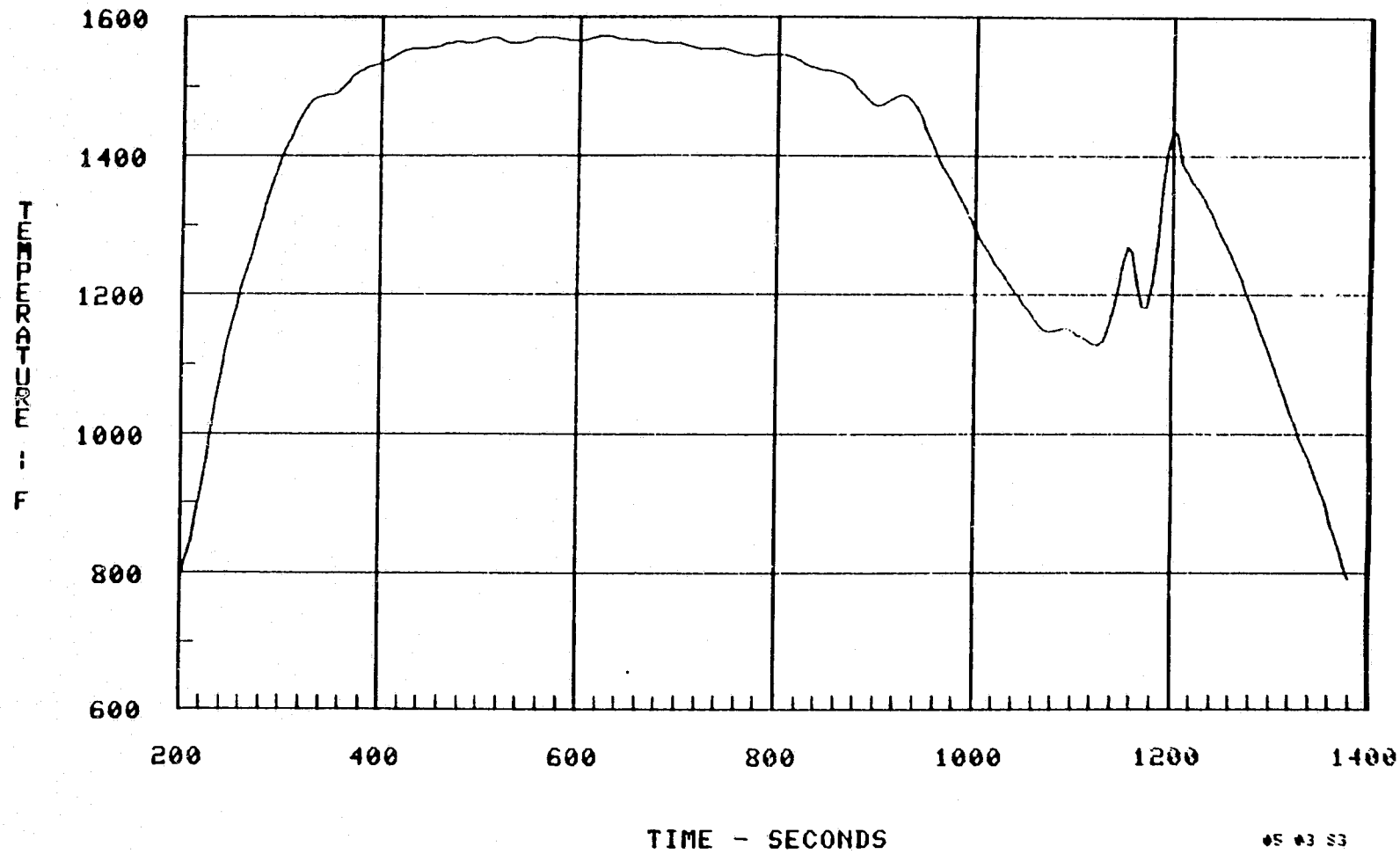

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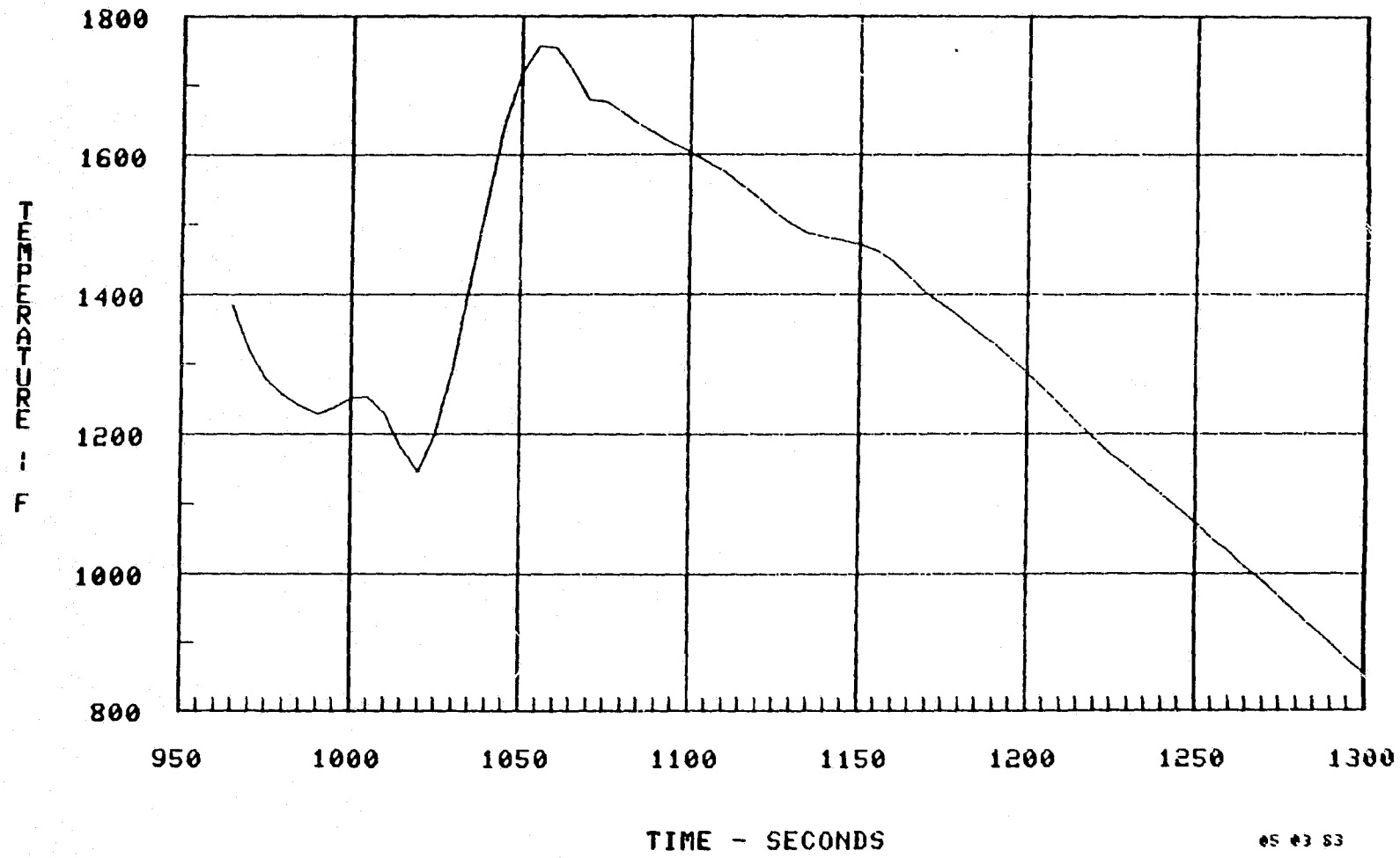

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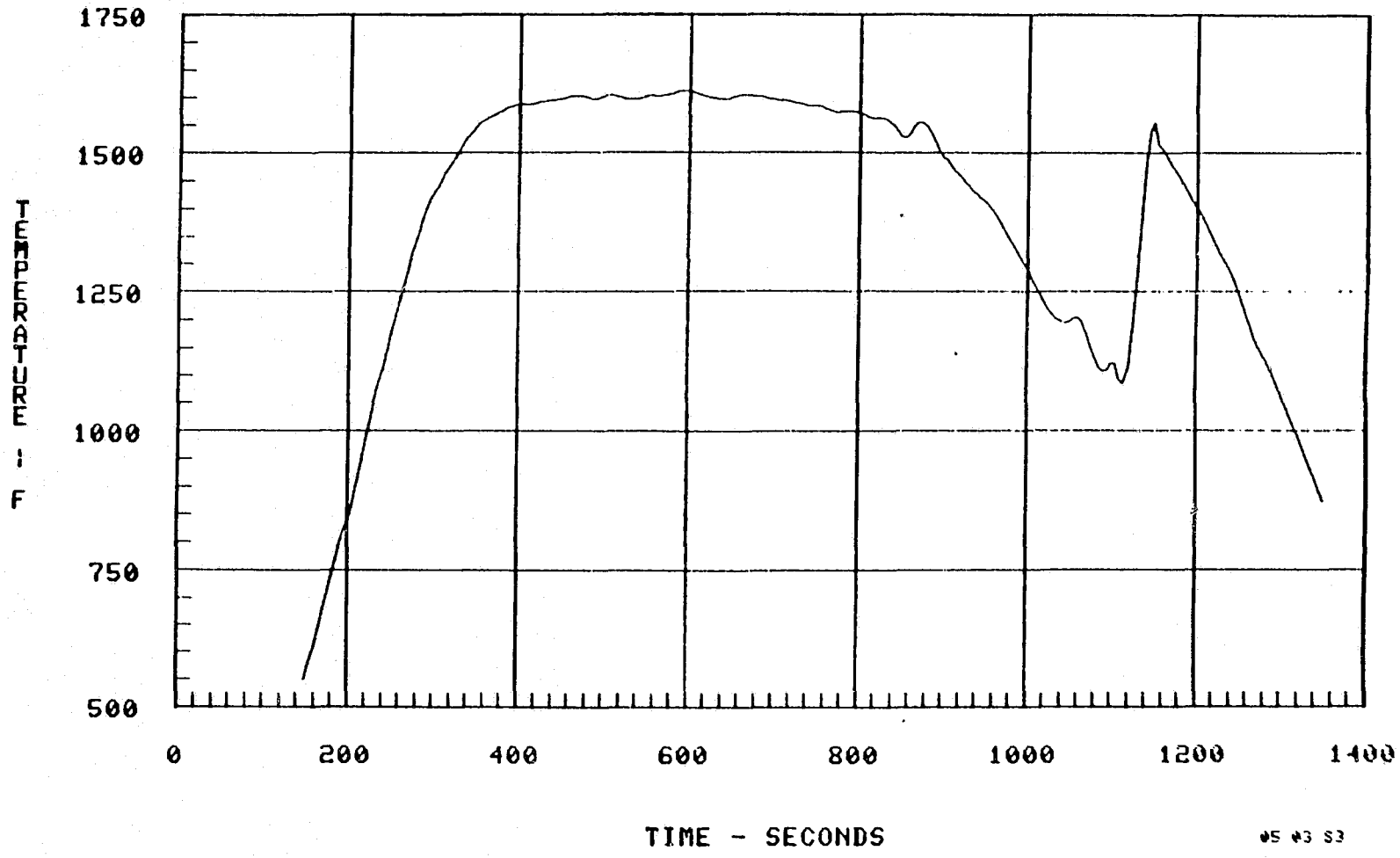

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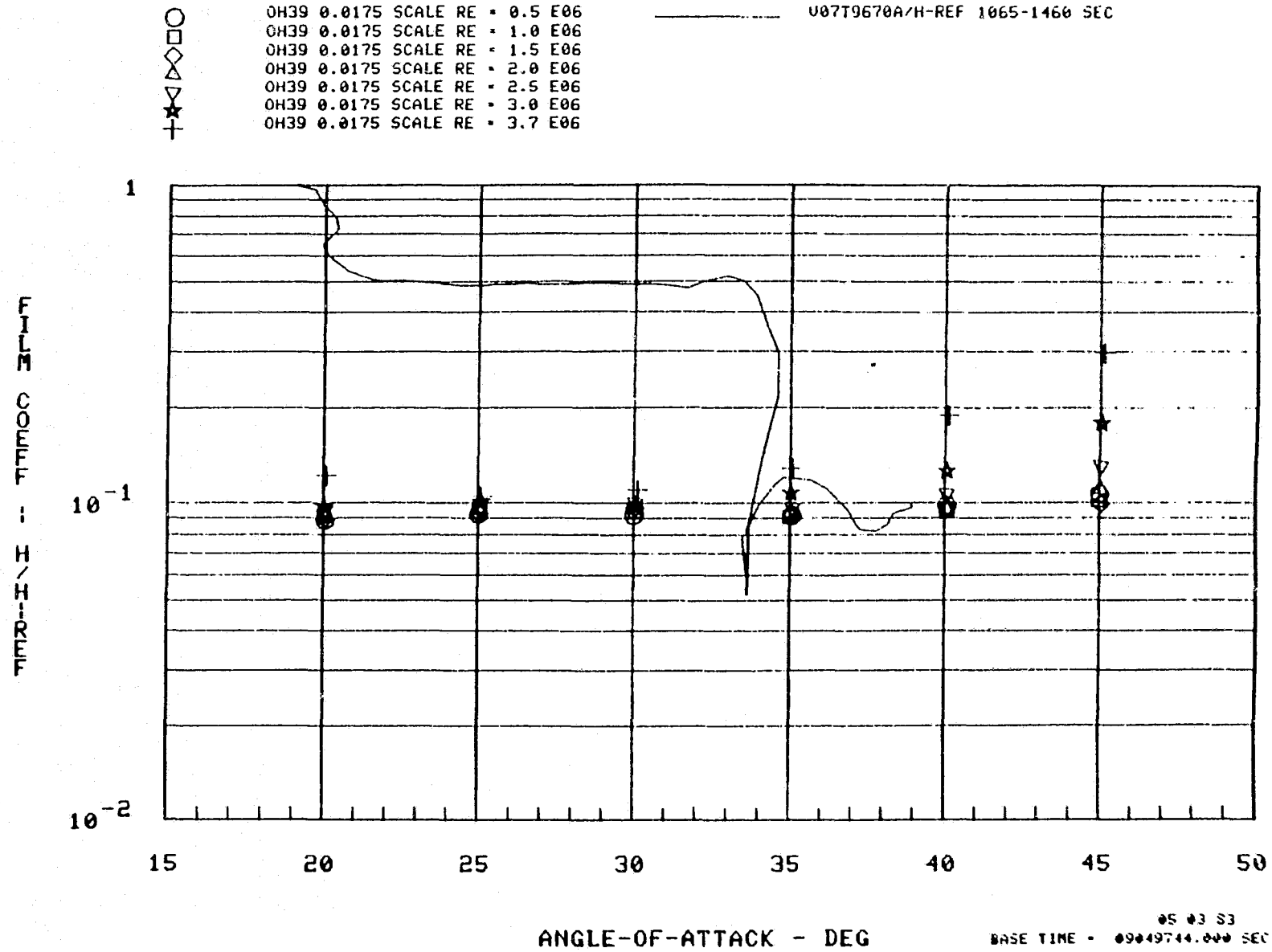

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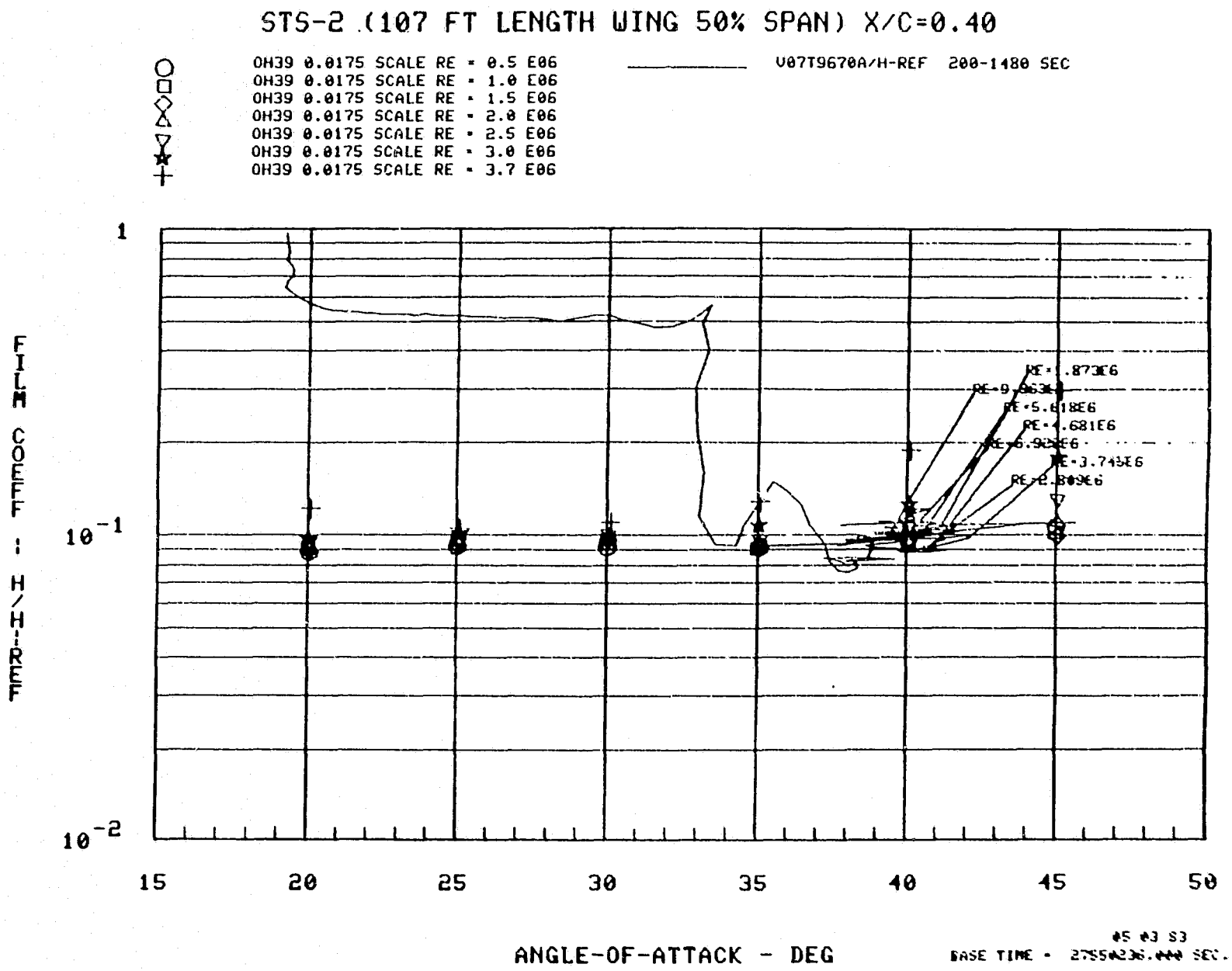
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FILM COEFF - H/H-REF
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20
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ANGLE-OF-ATTACK - DEG
05 03 S3
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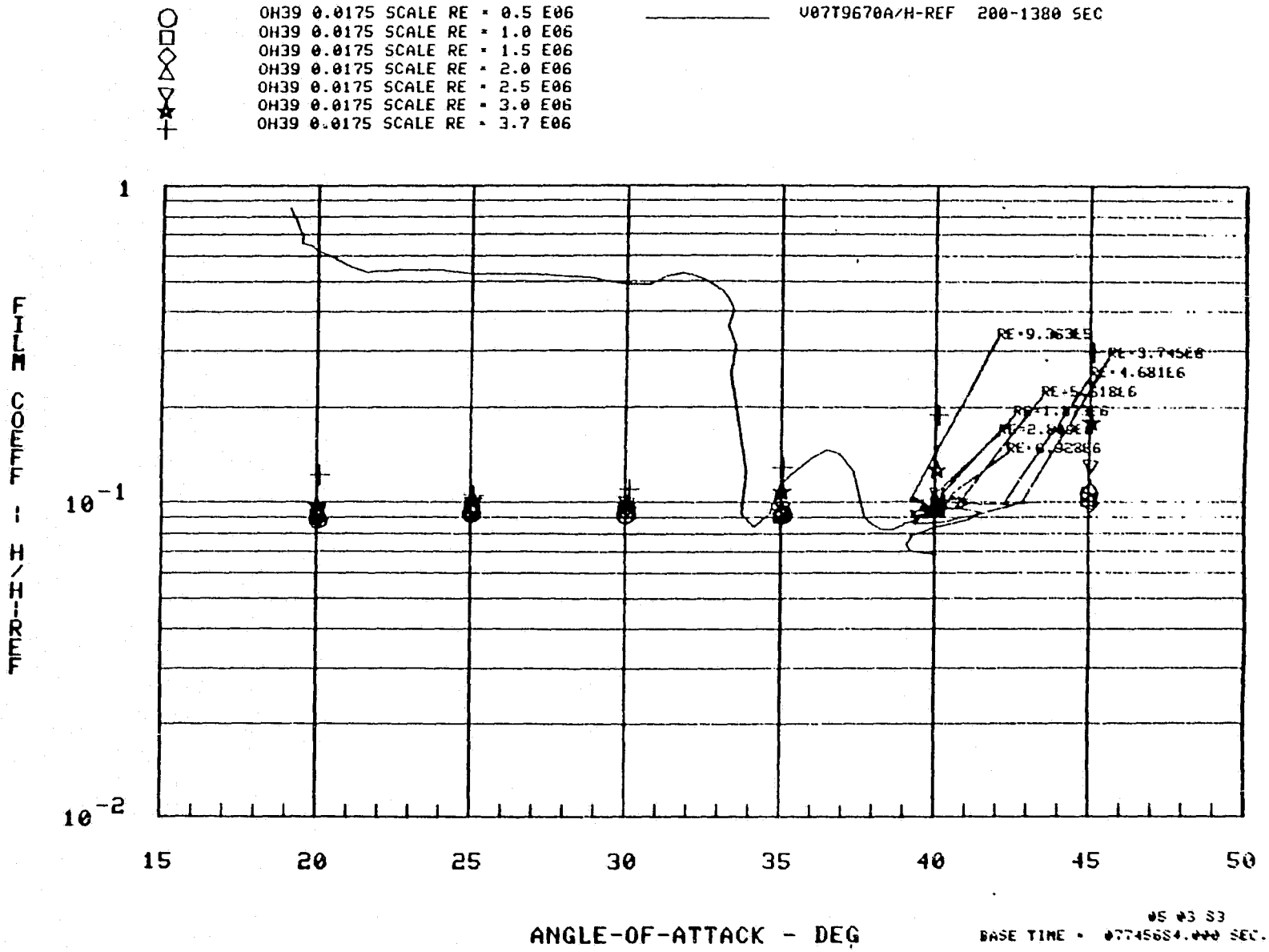

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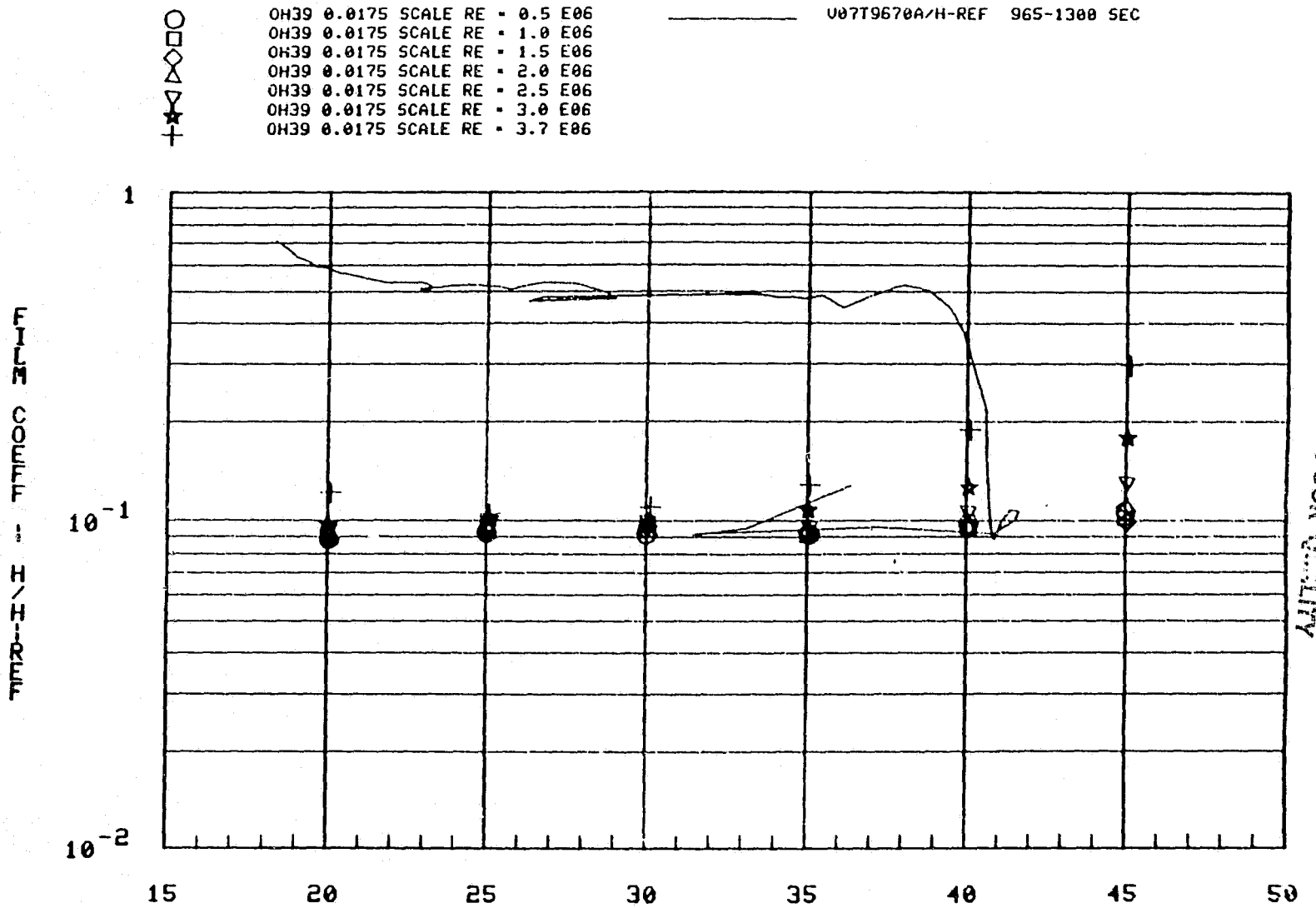

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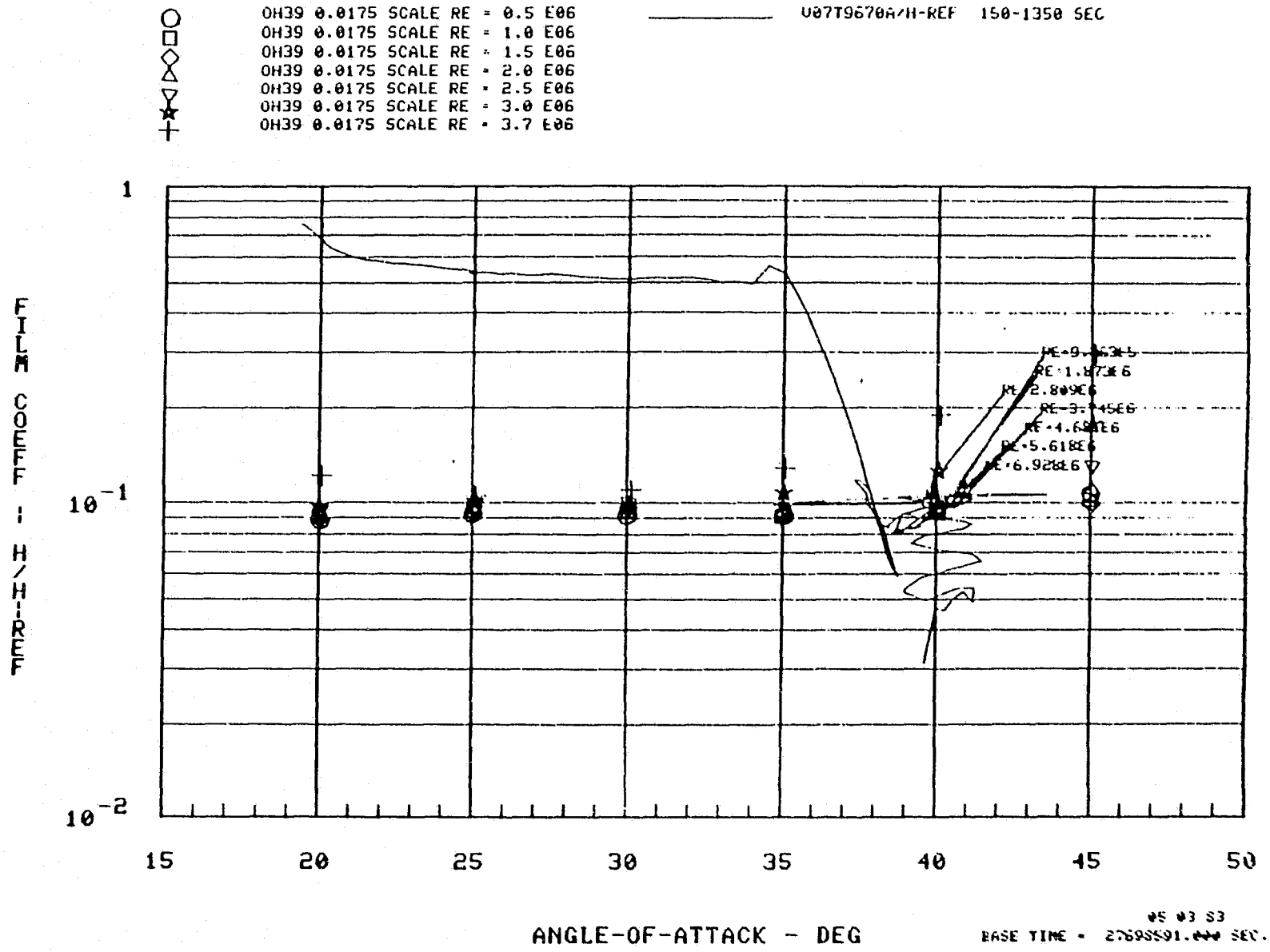

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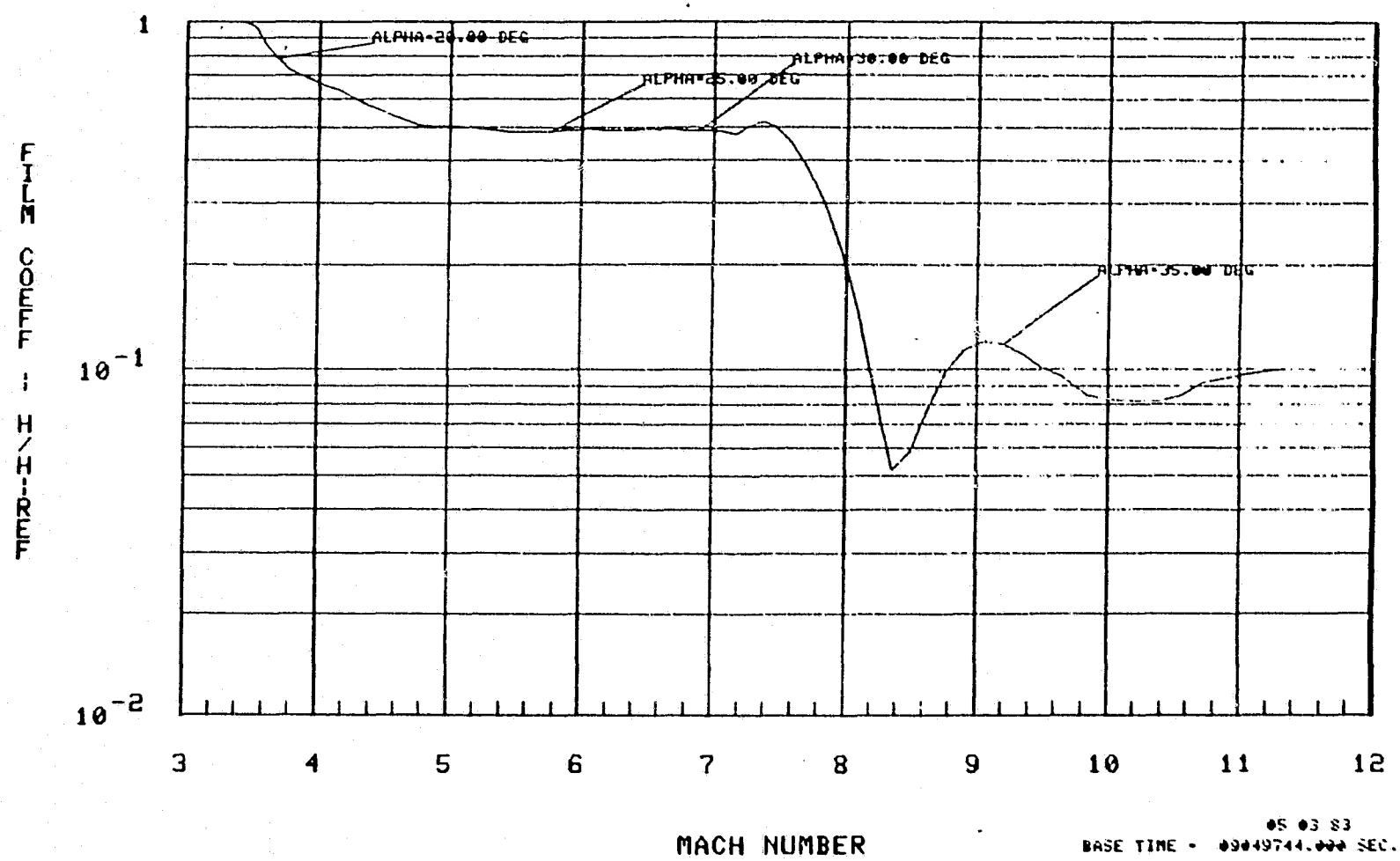

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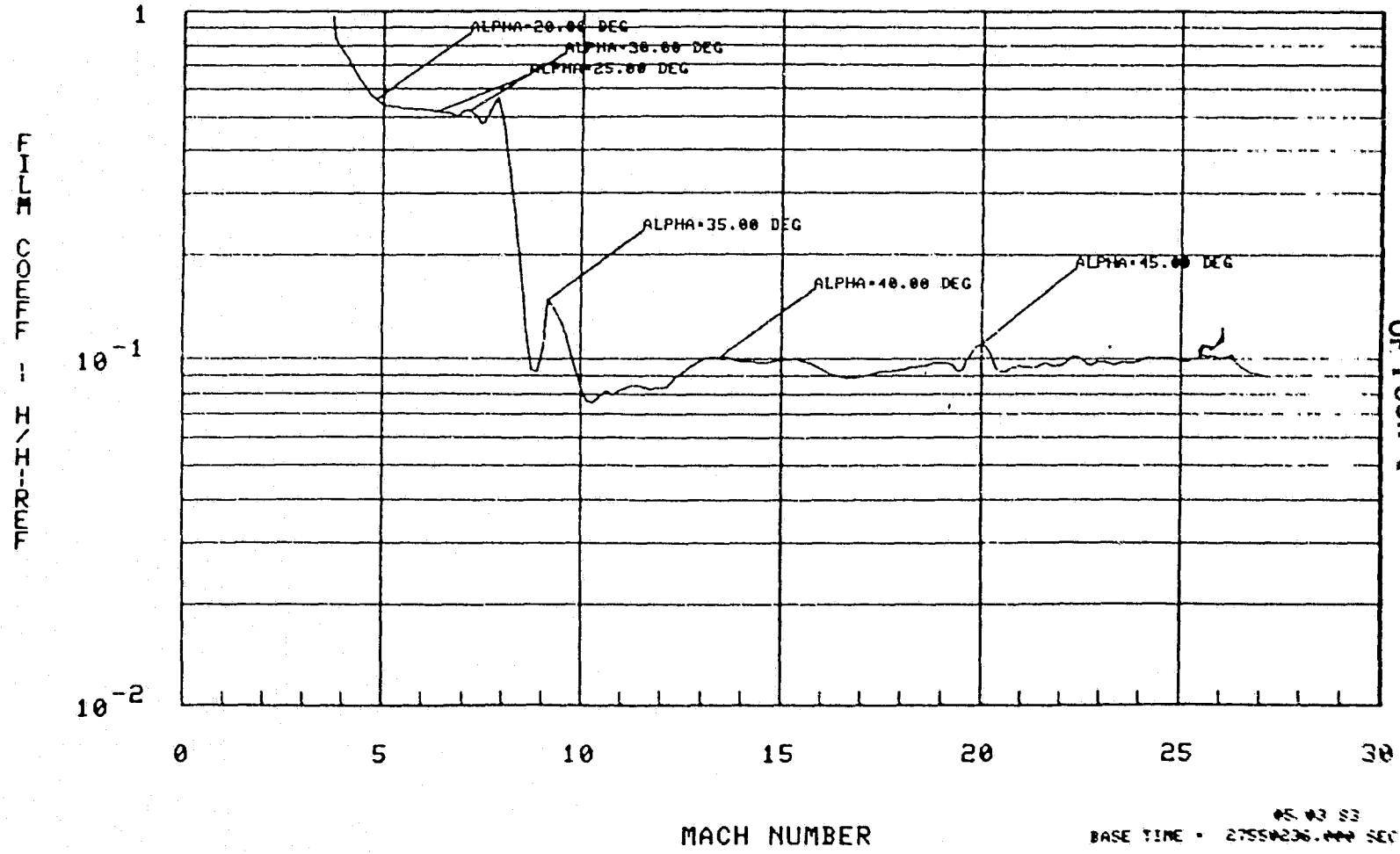

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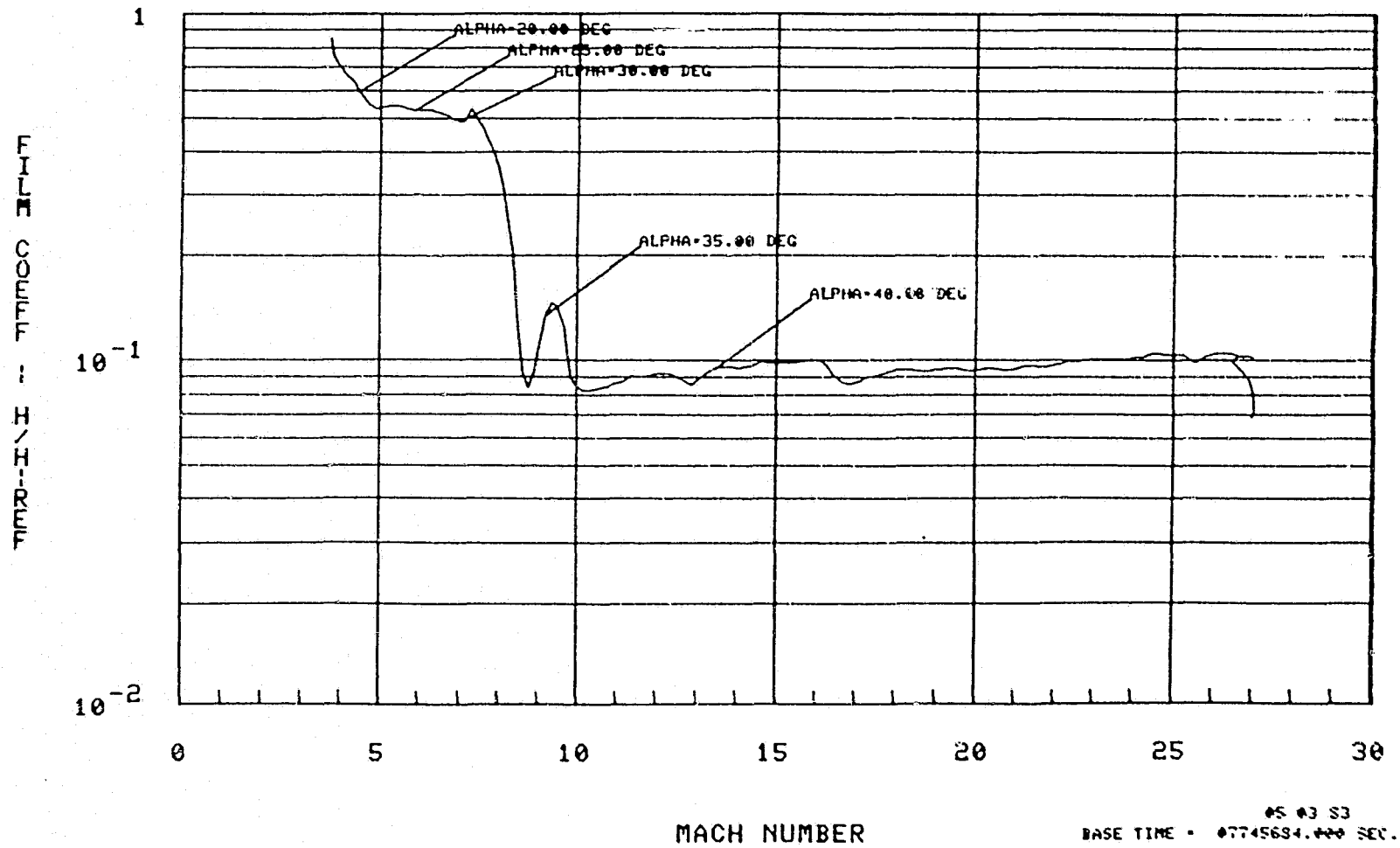

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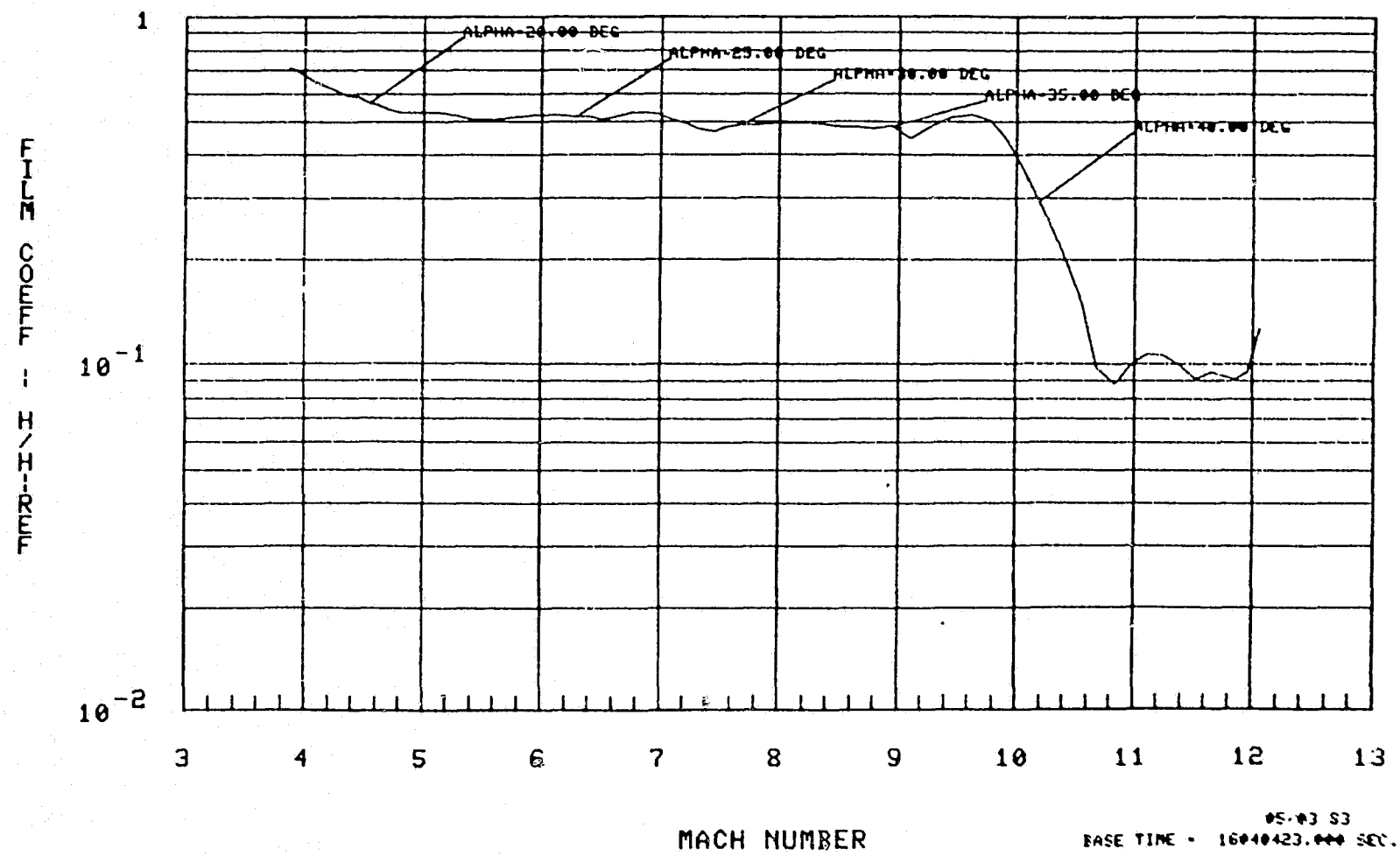

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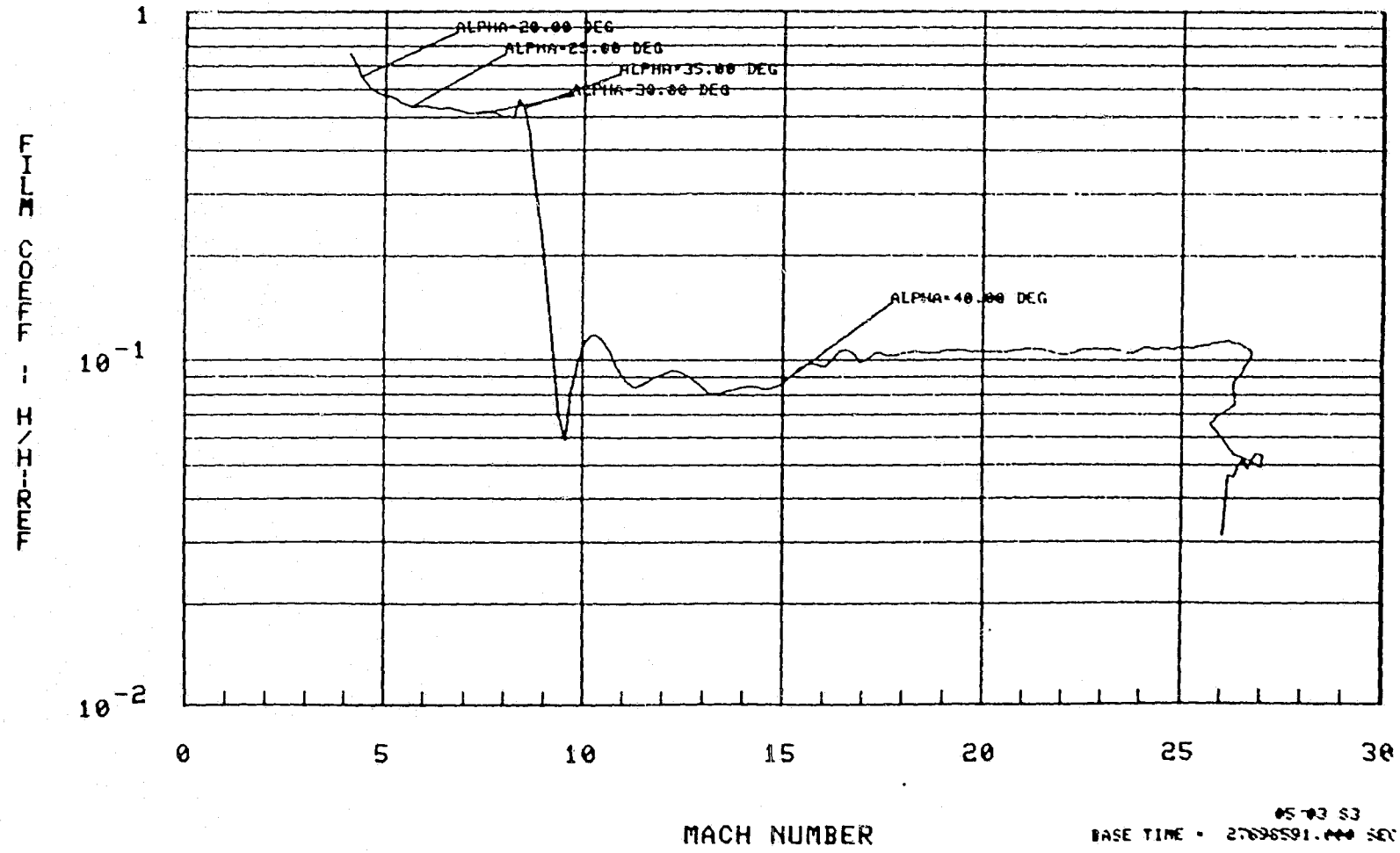

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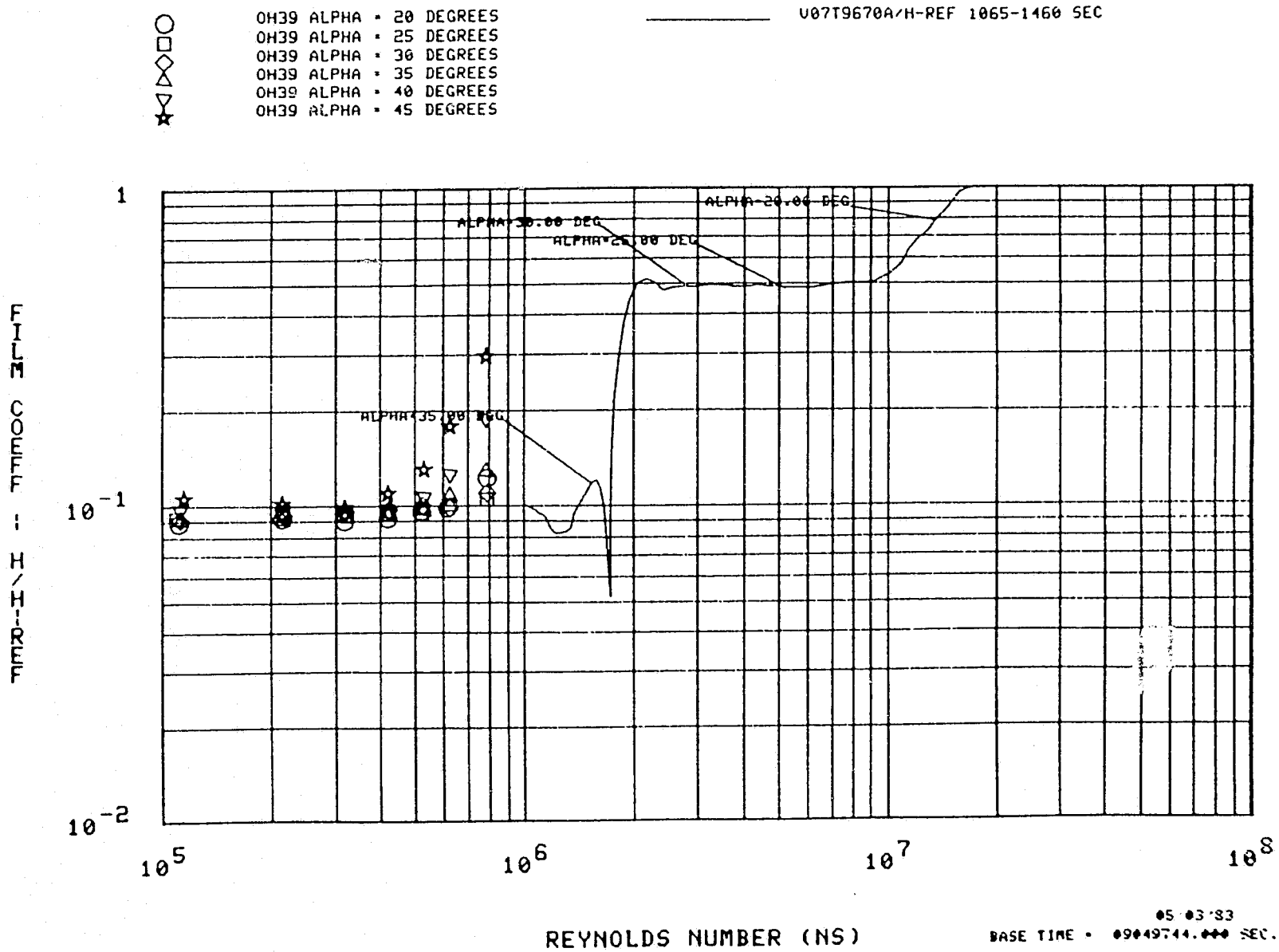

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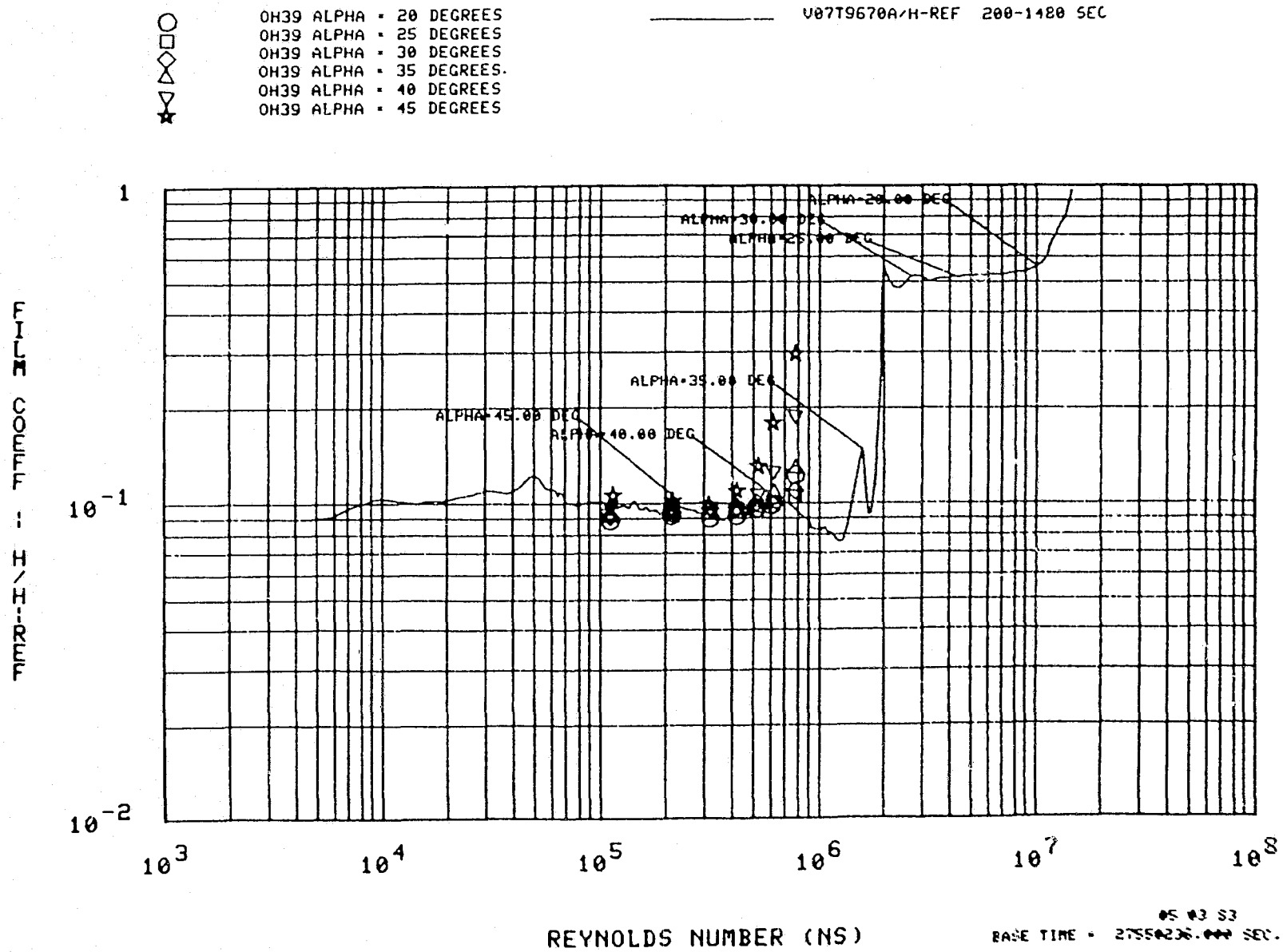

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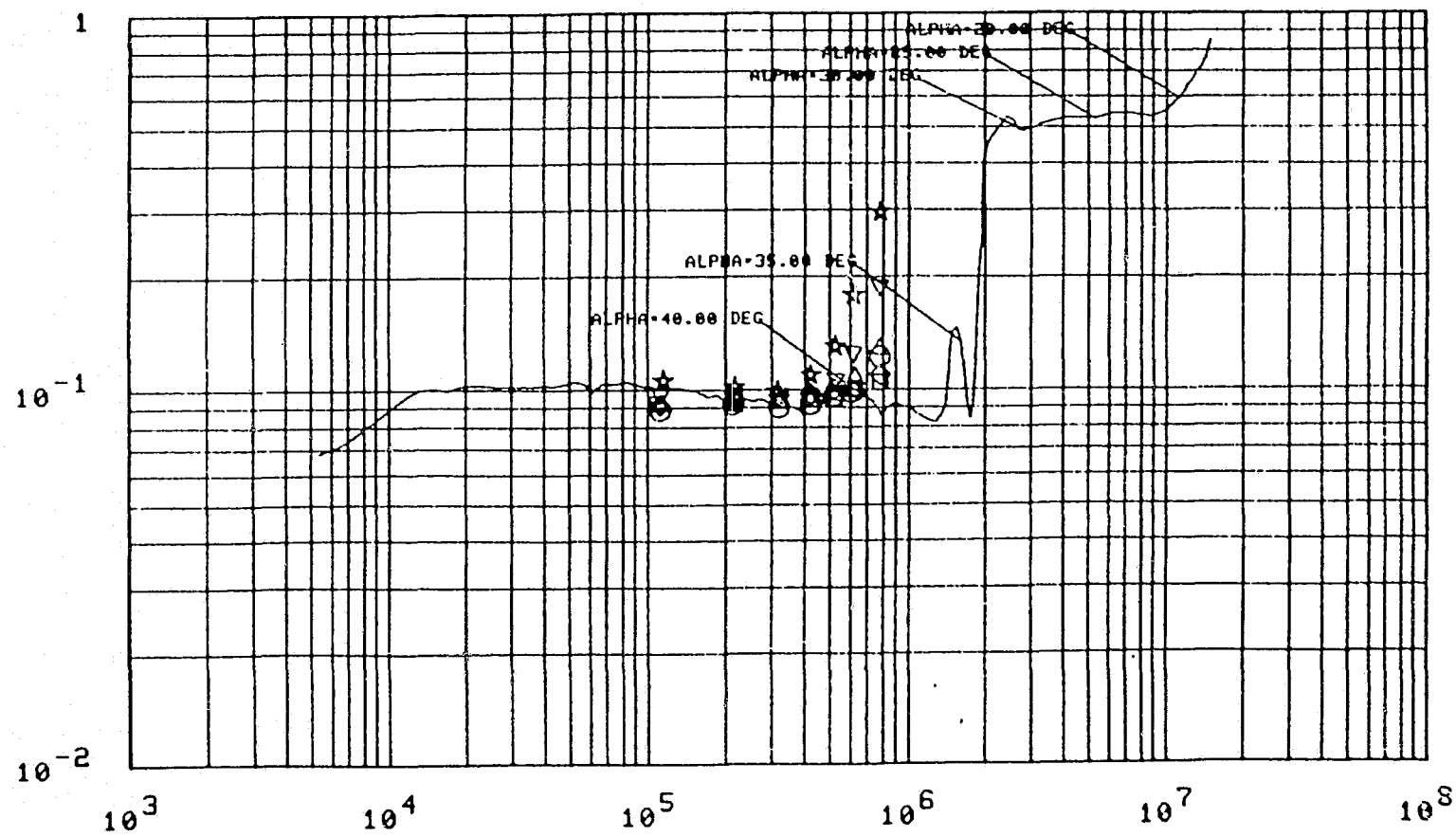

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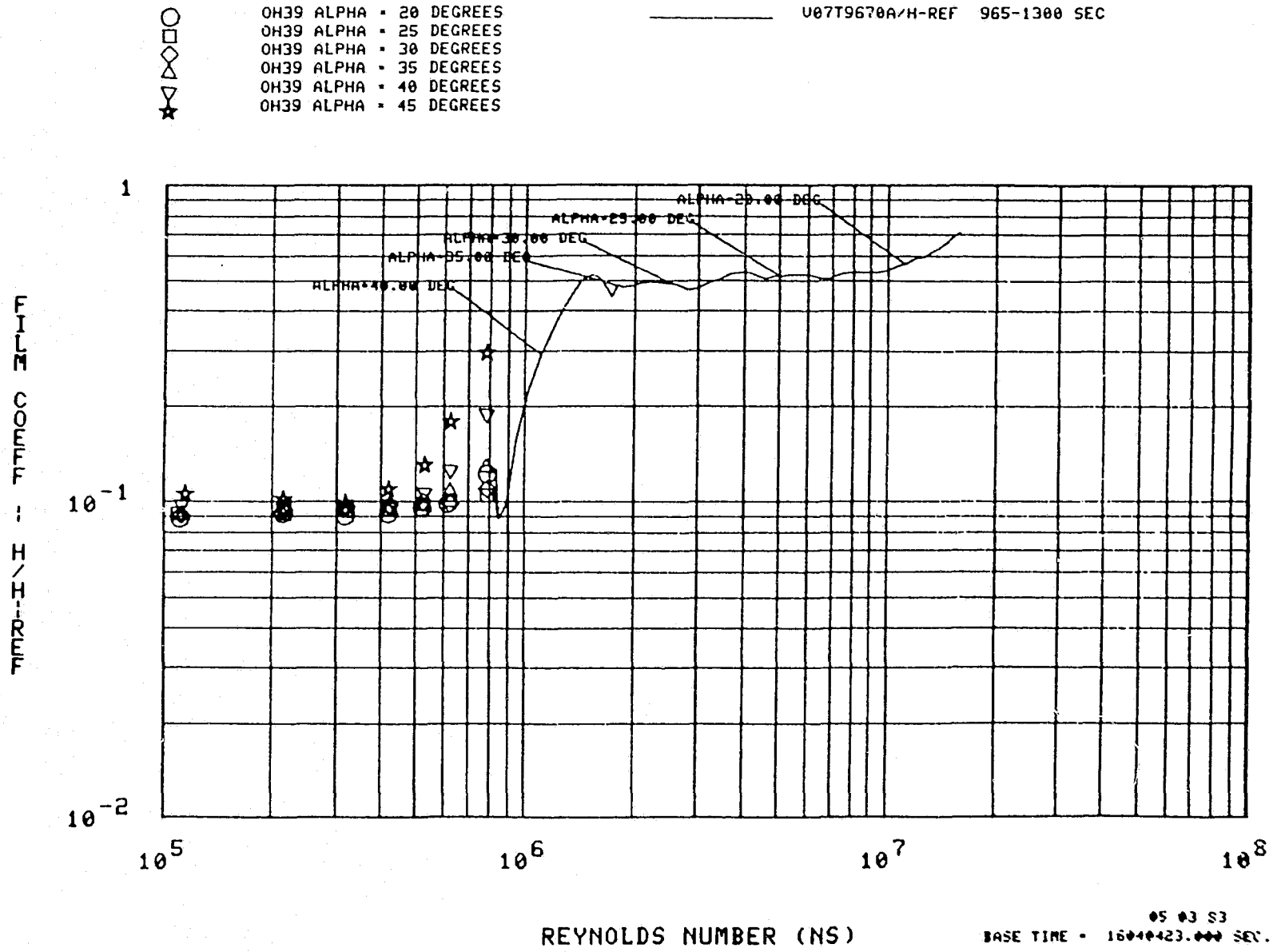

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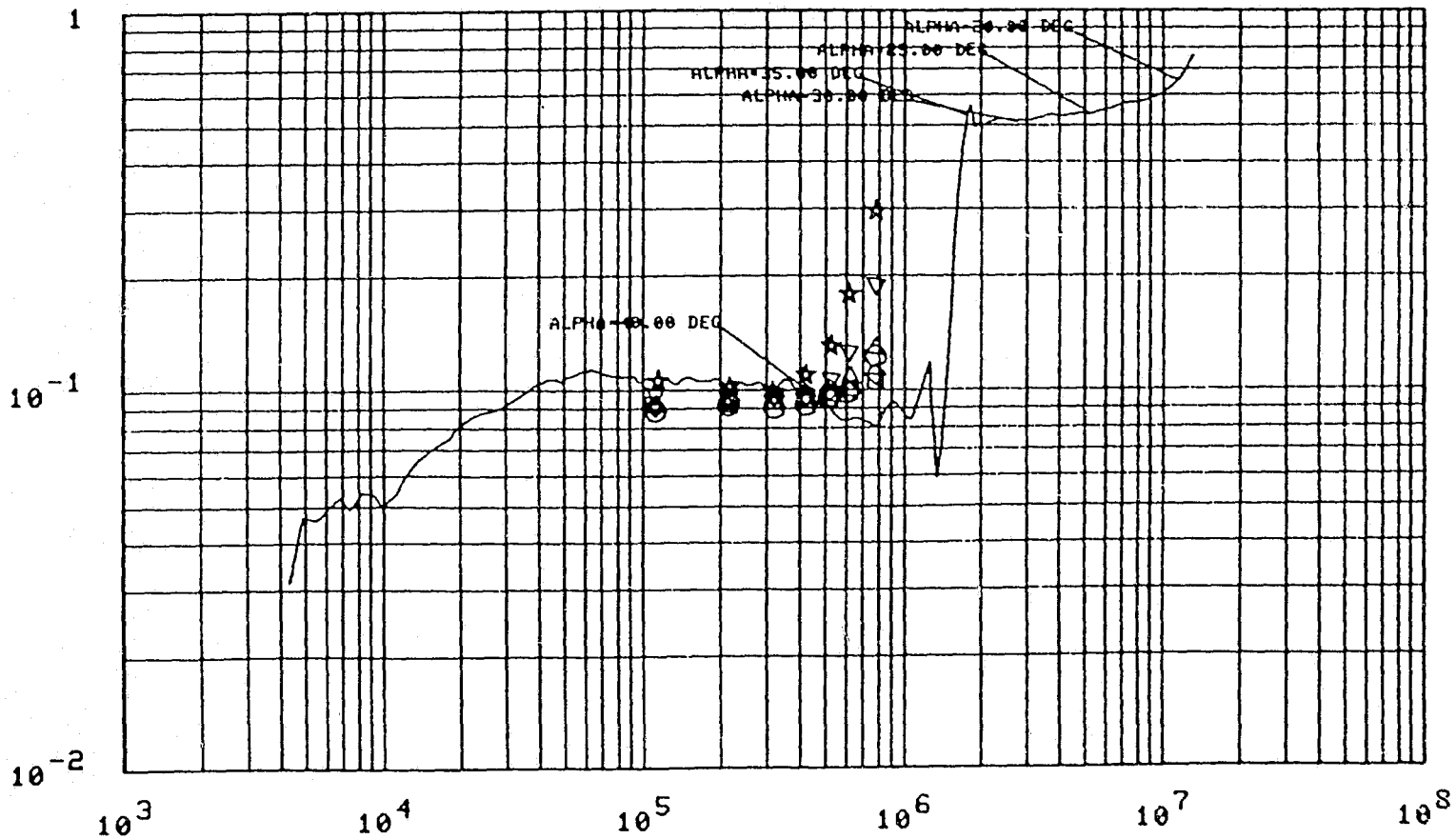

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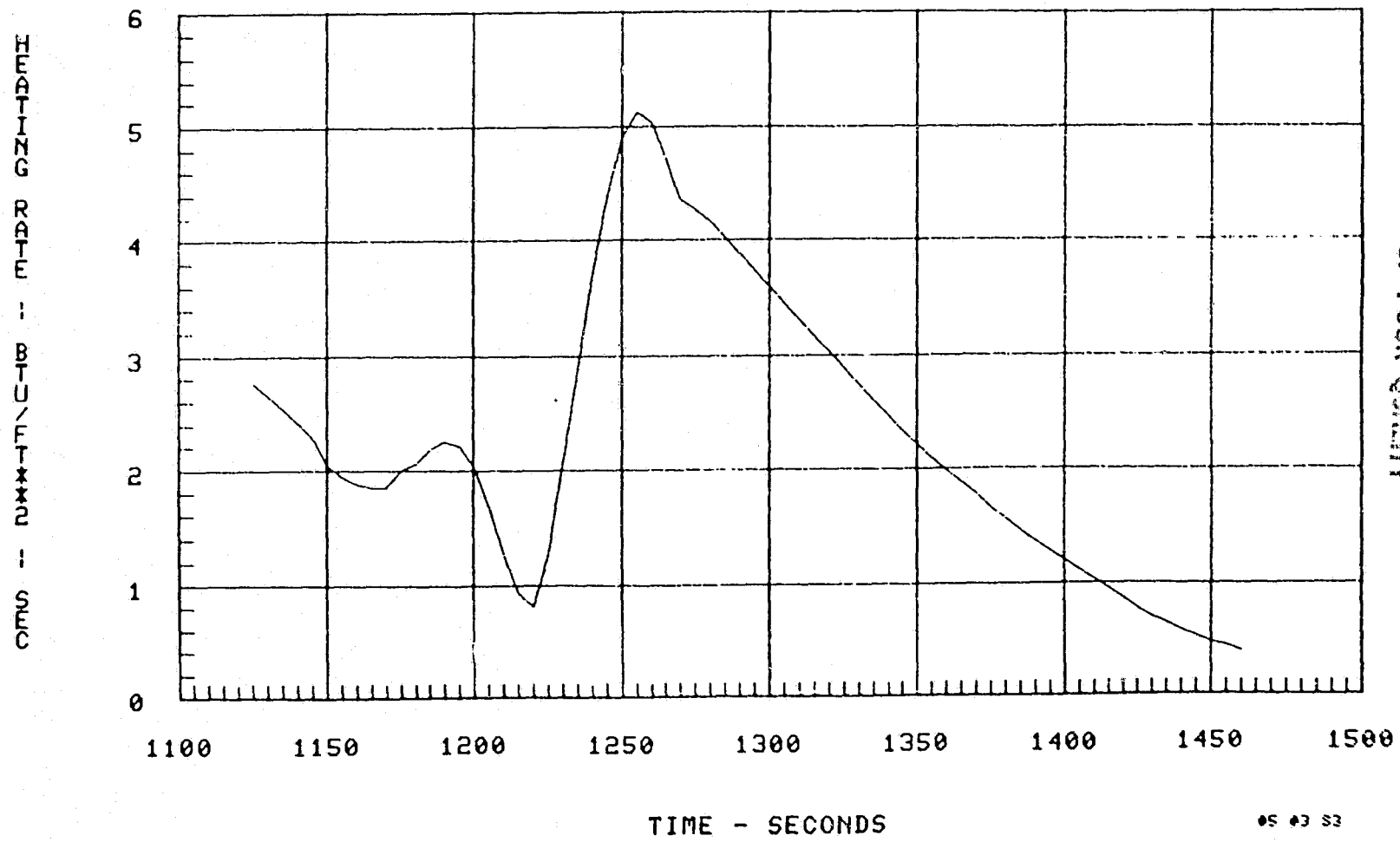

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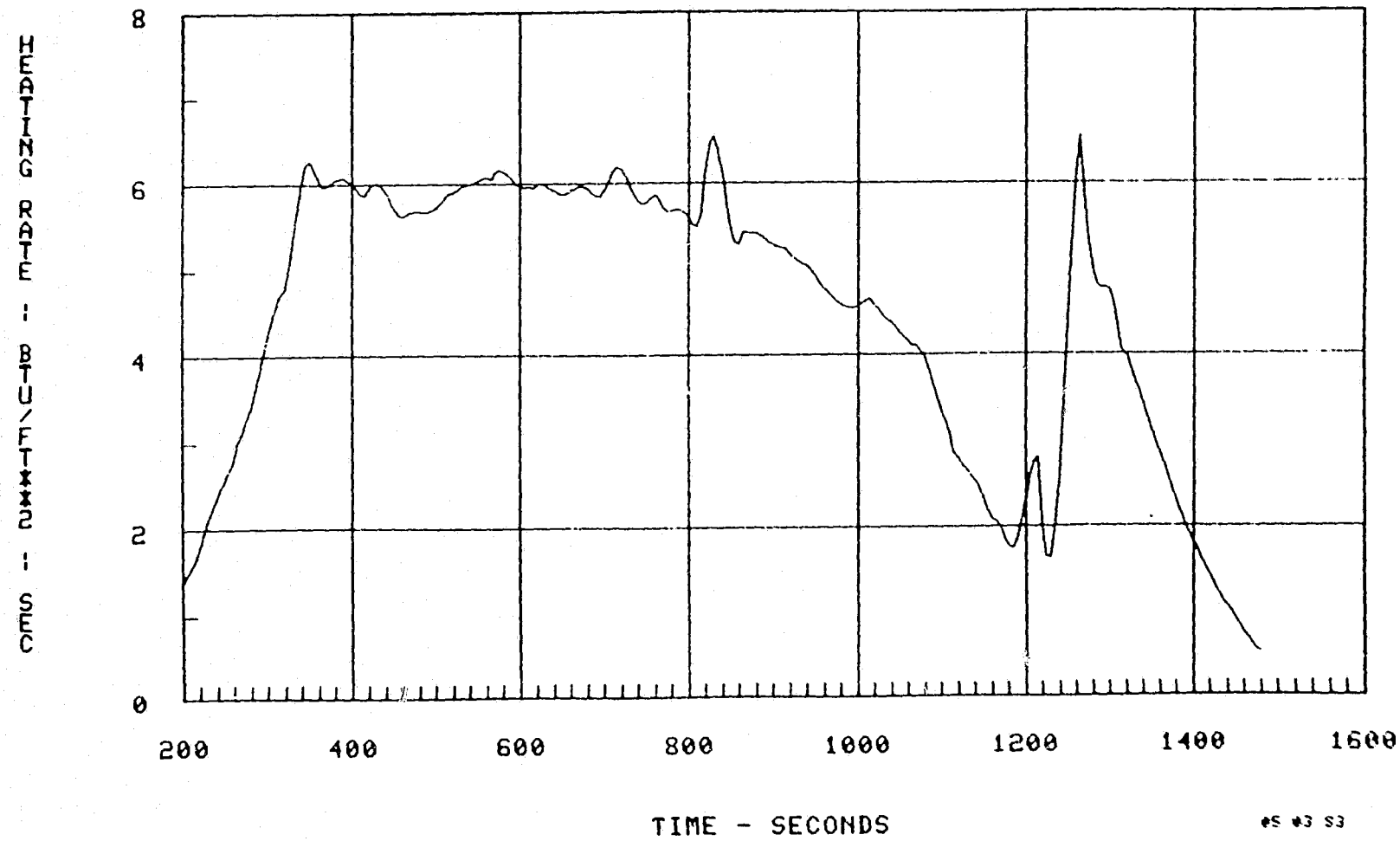

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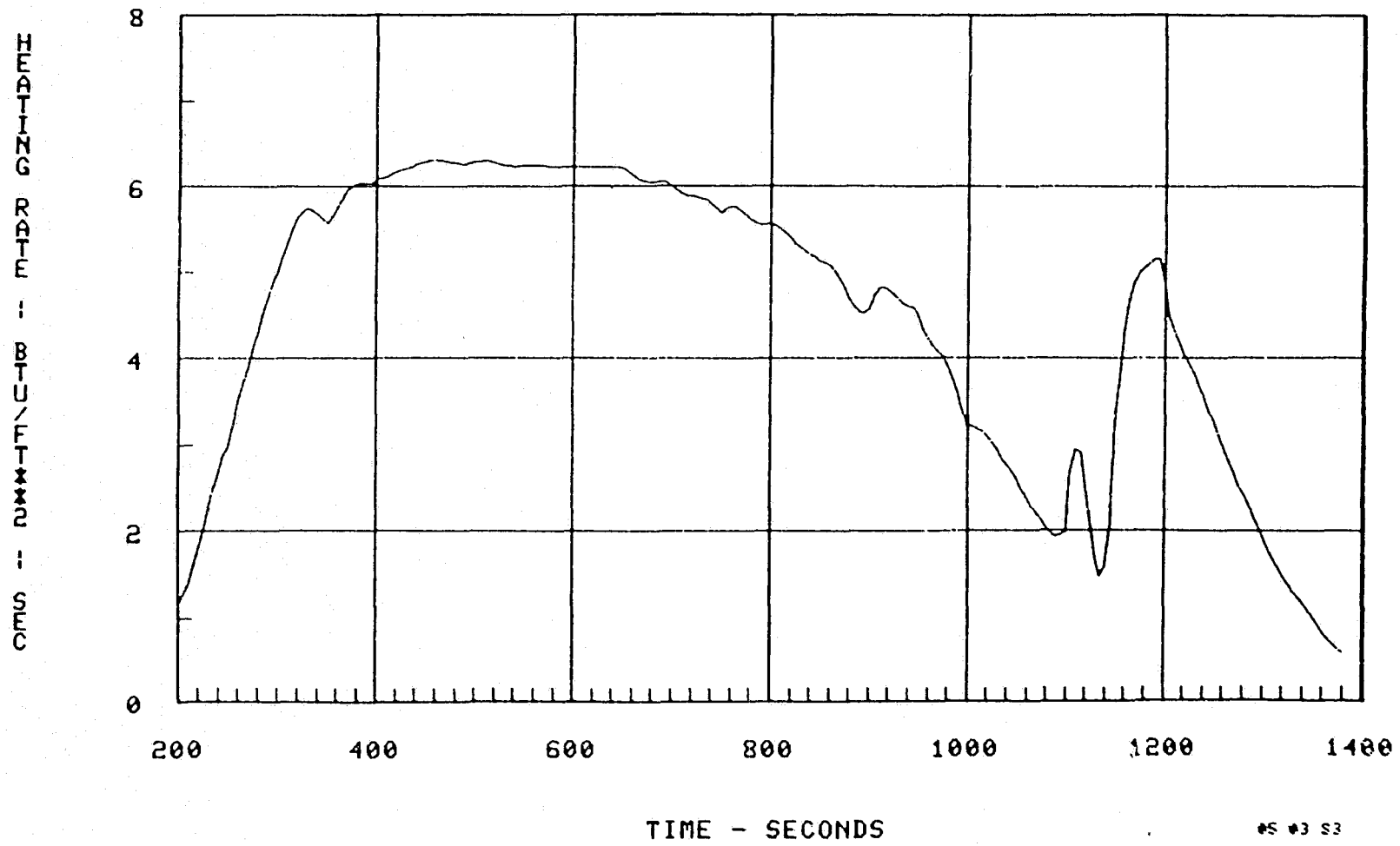

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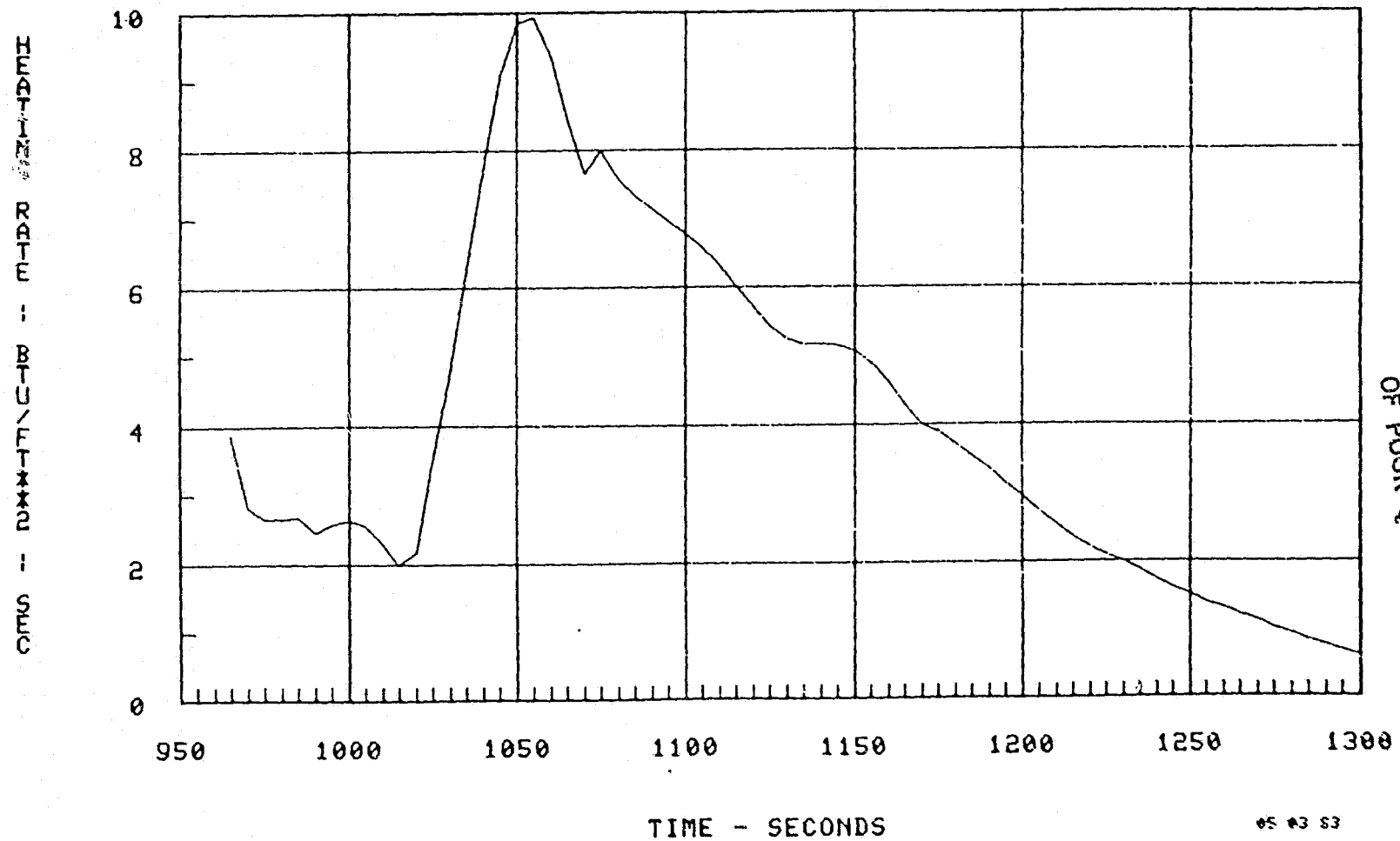

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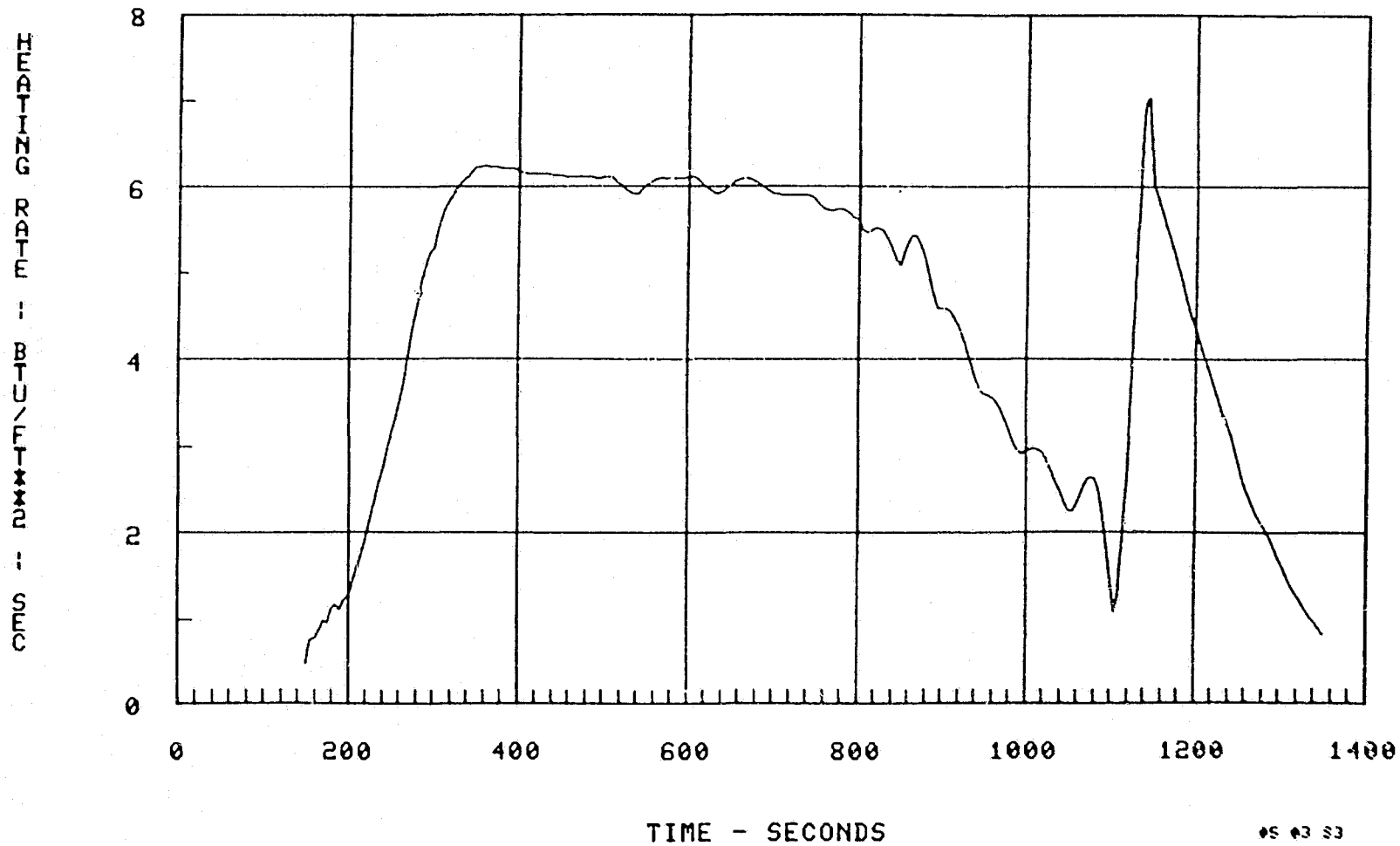

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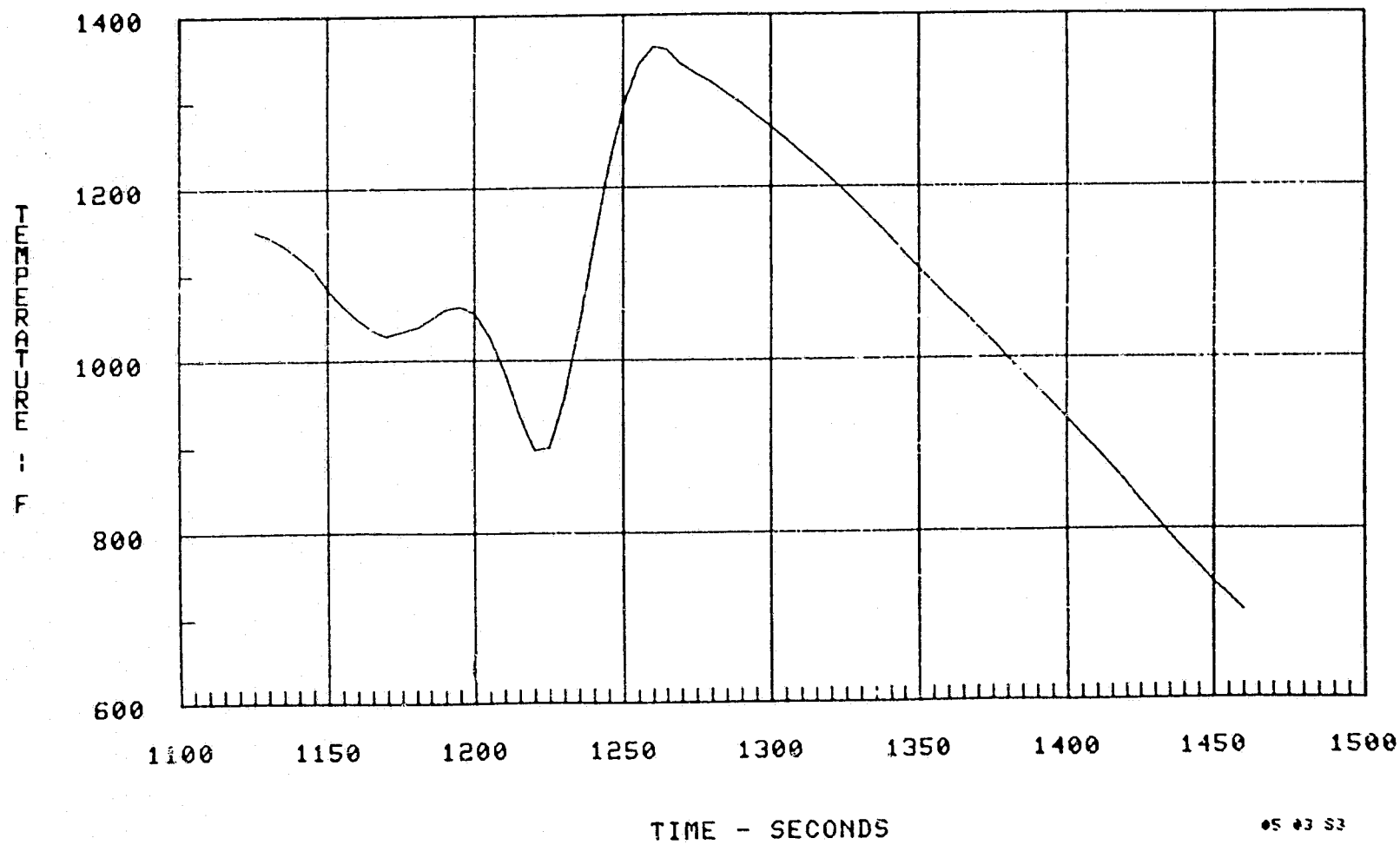

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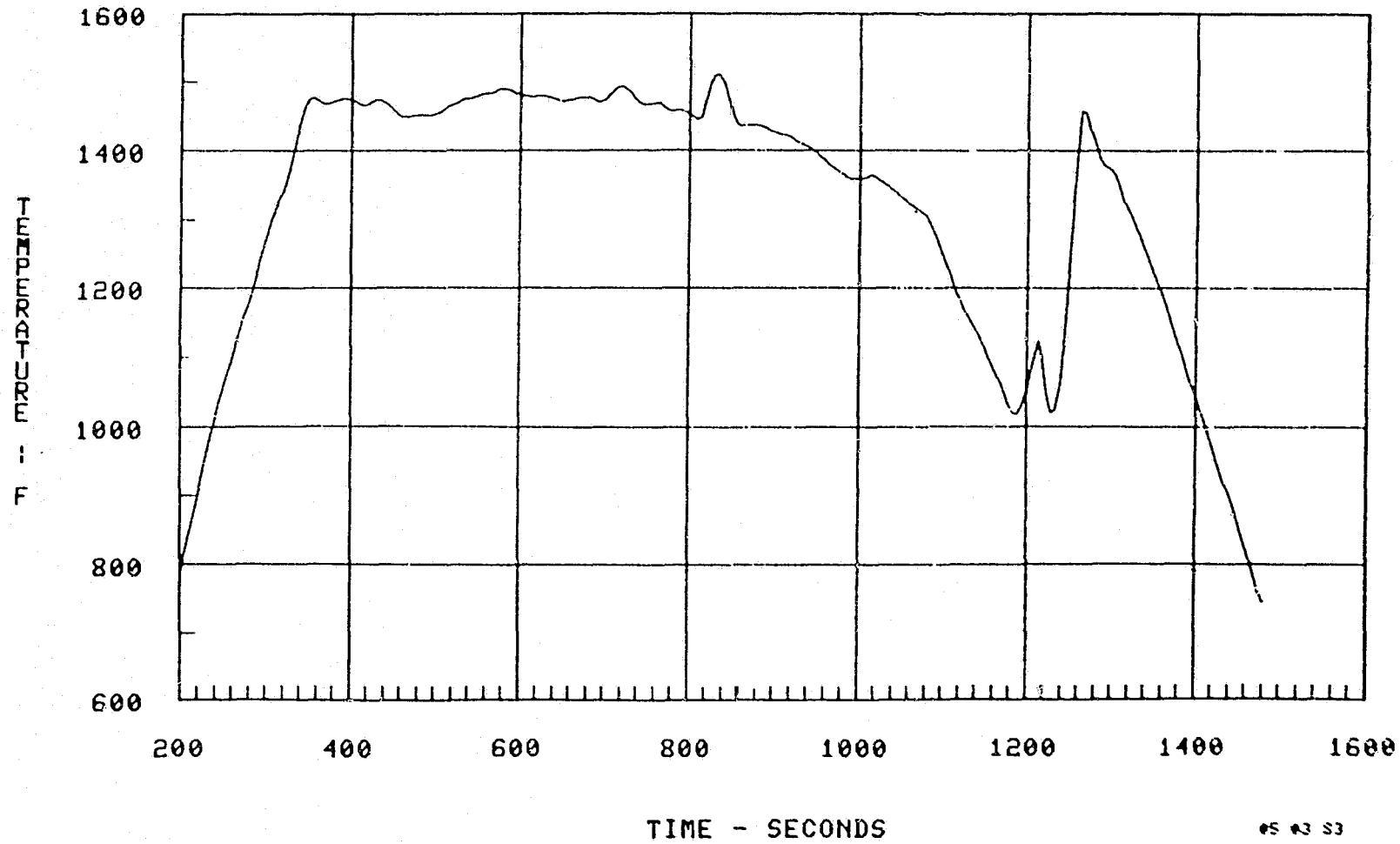

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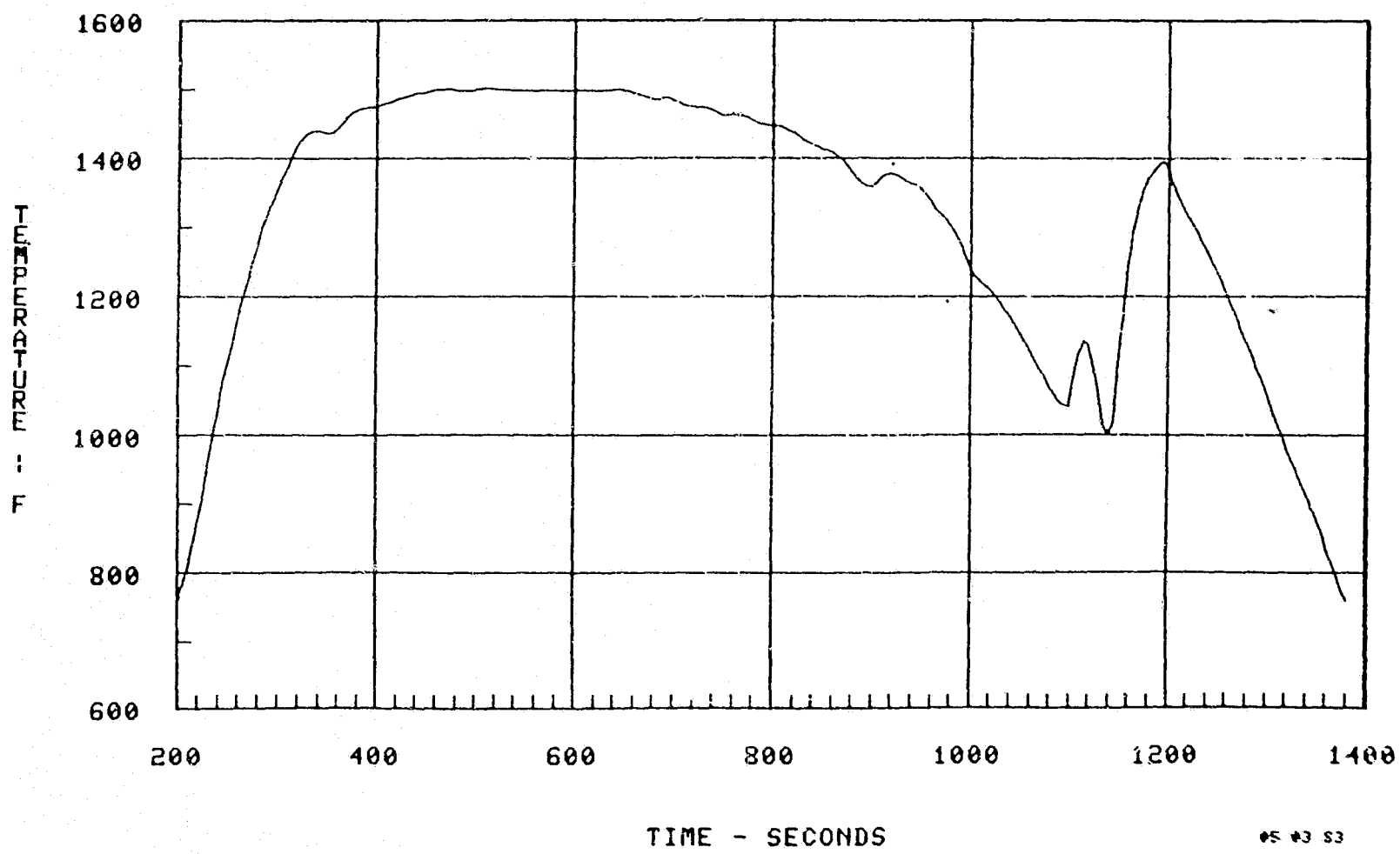

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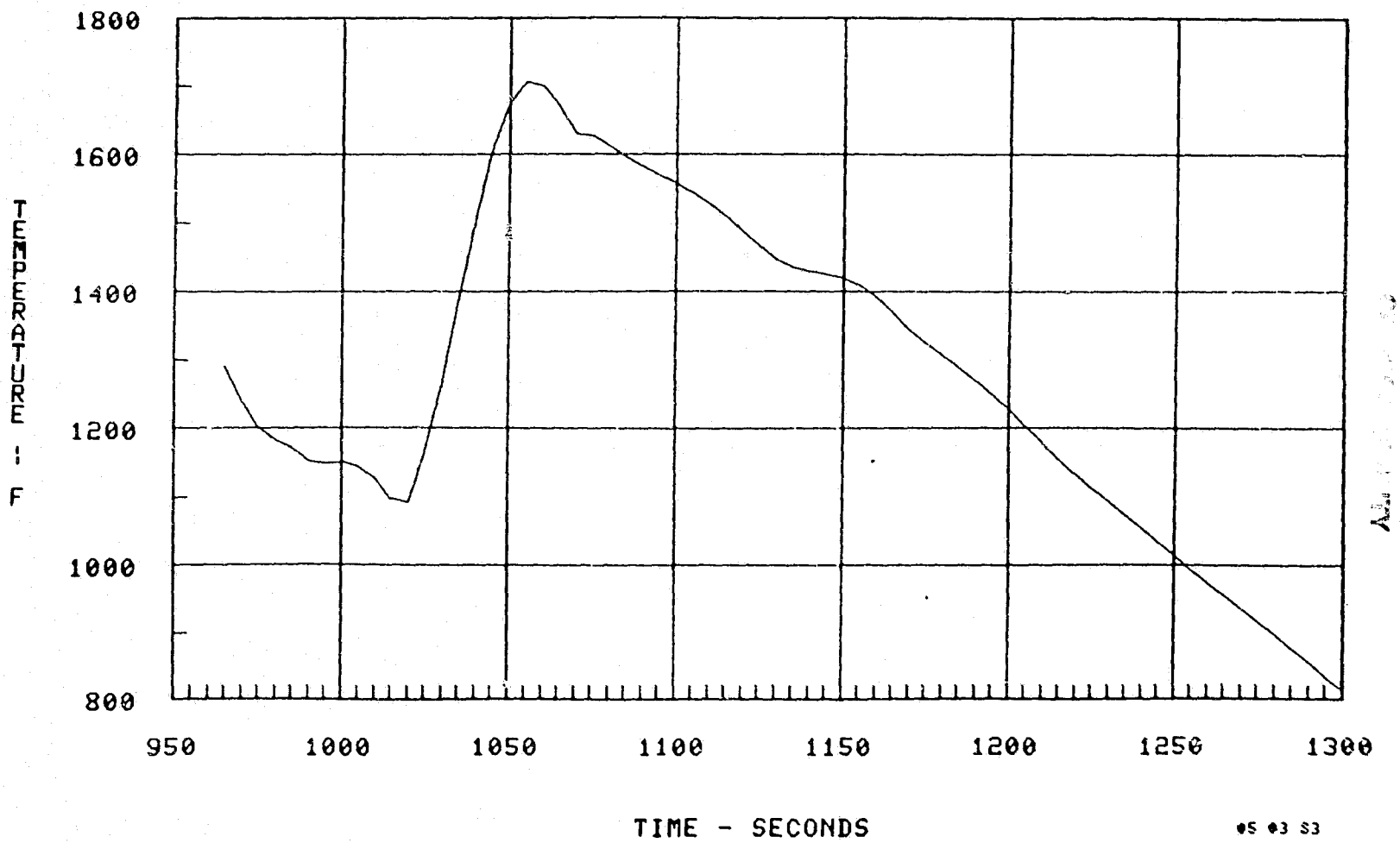

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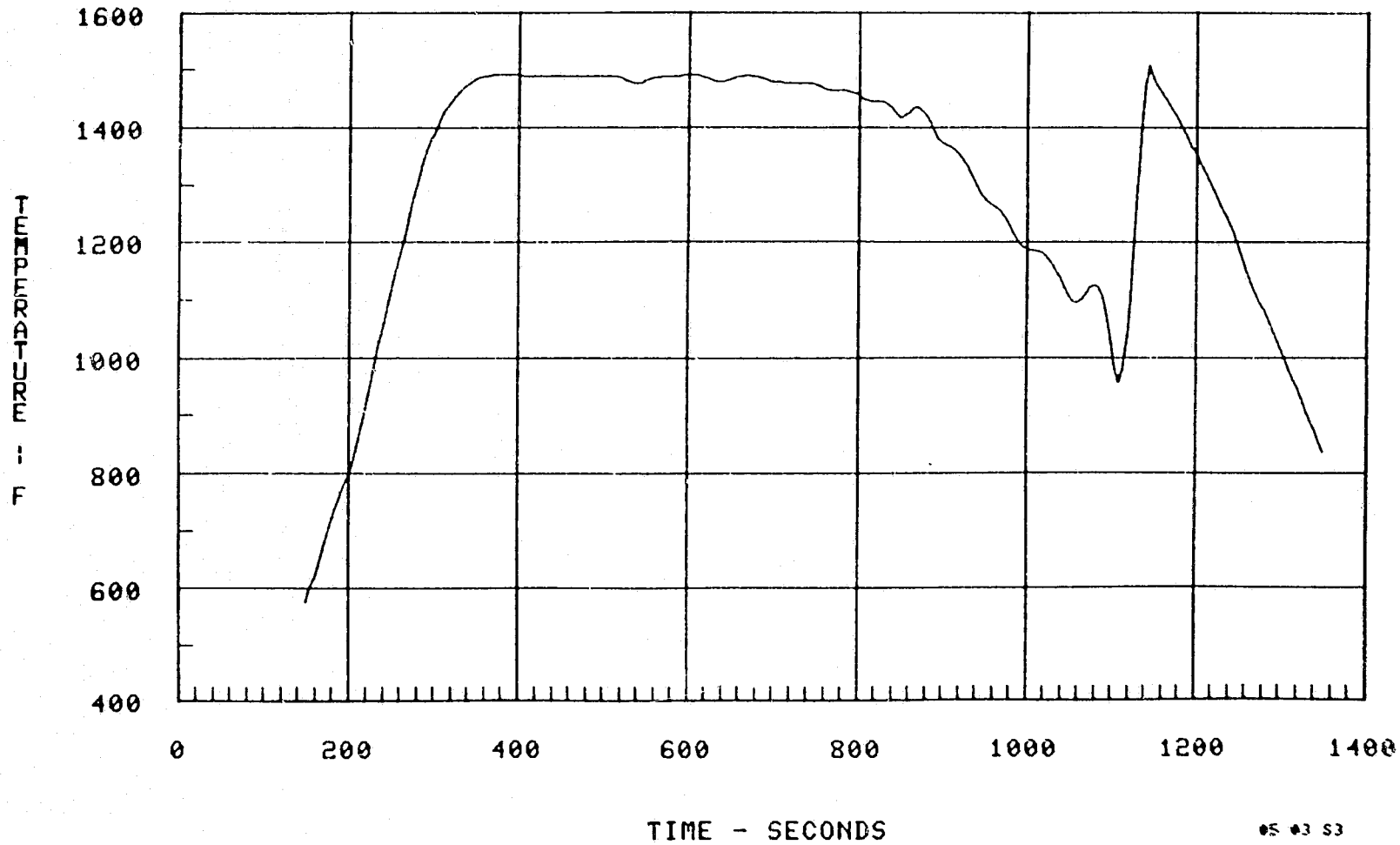

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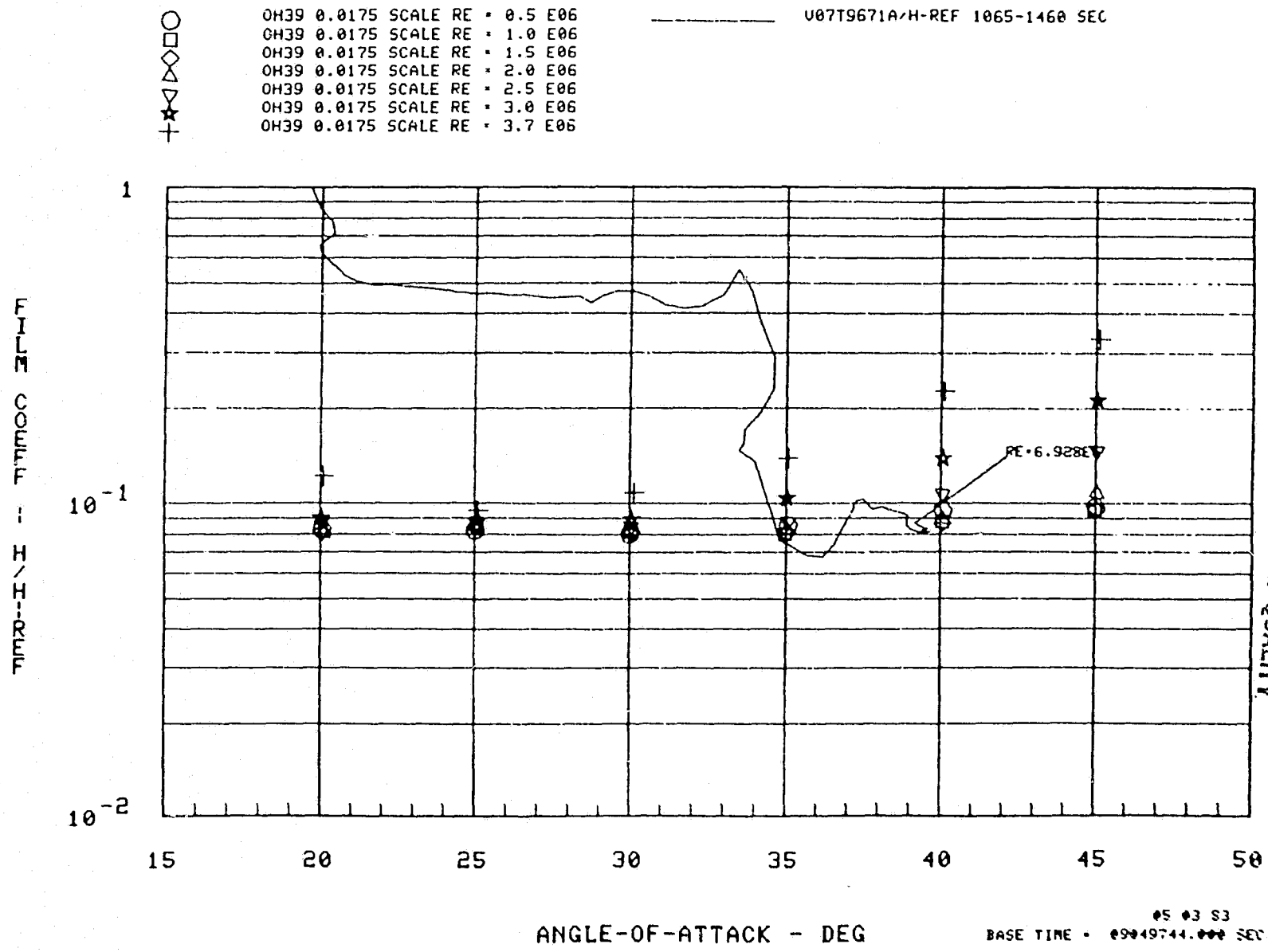

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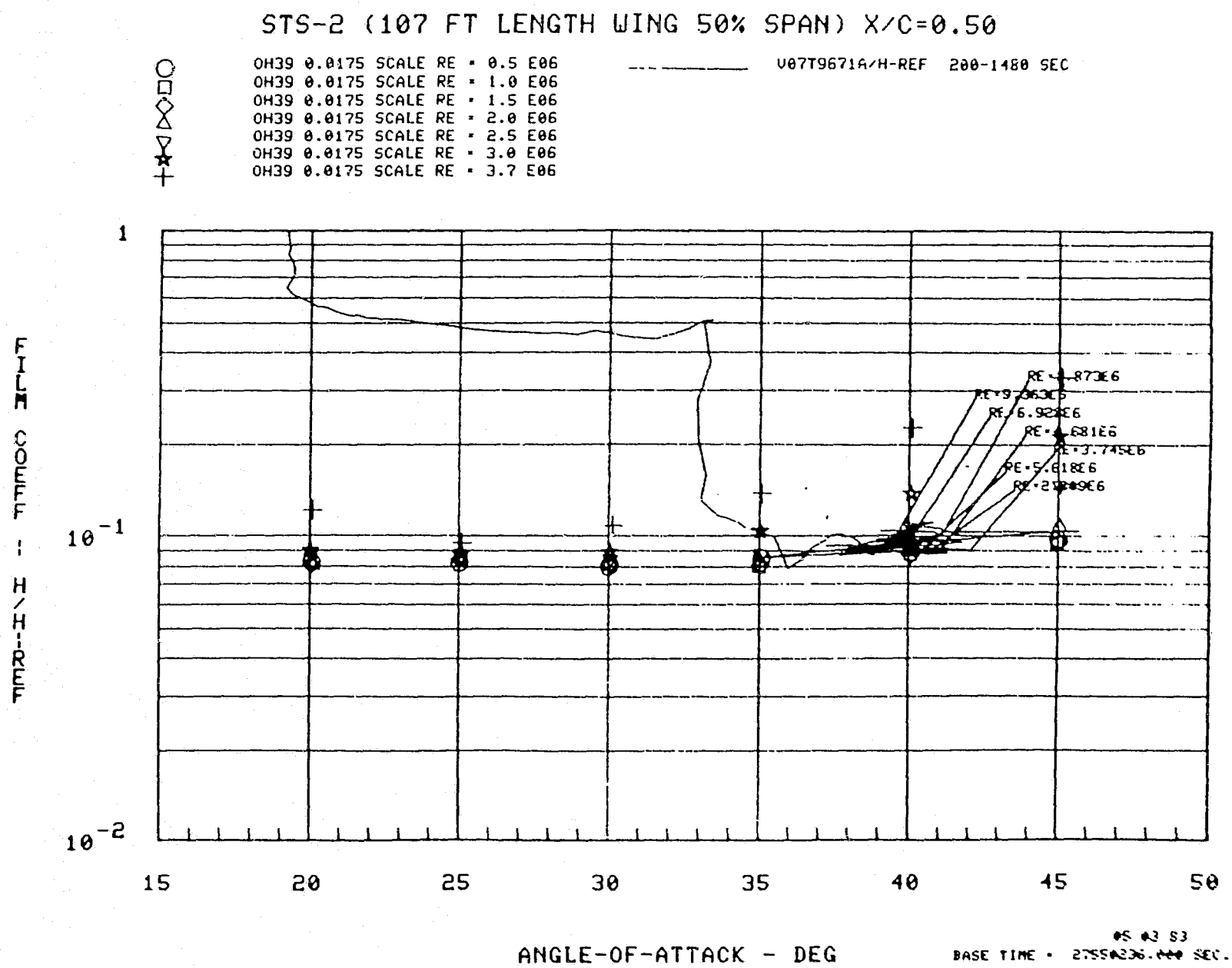

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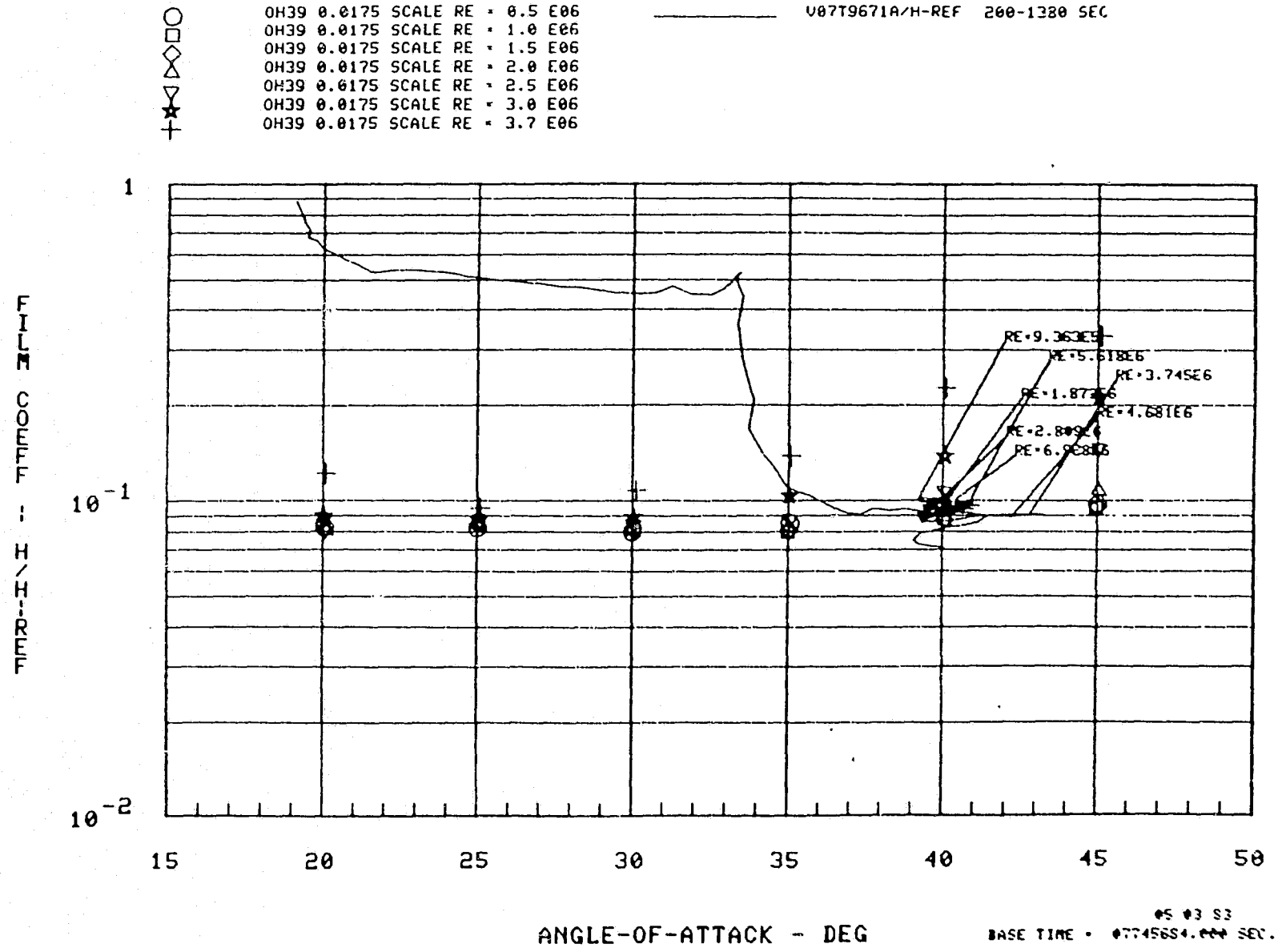

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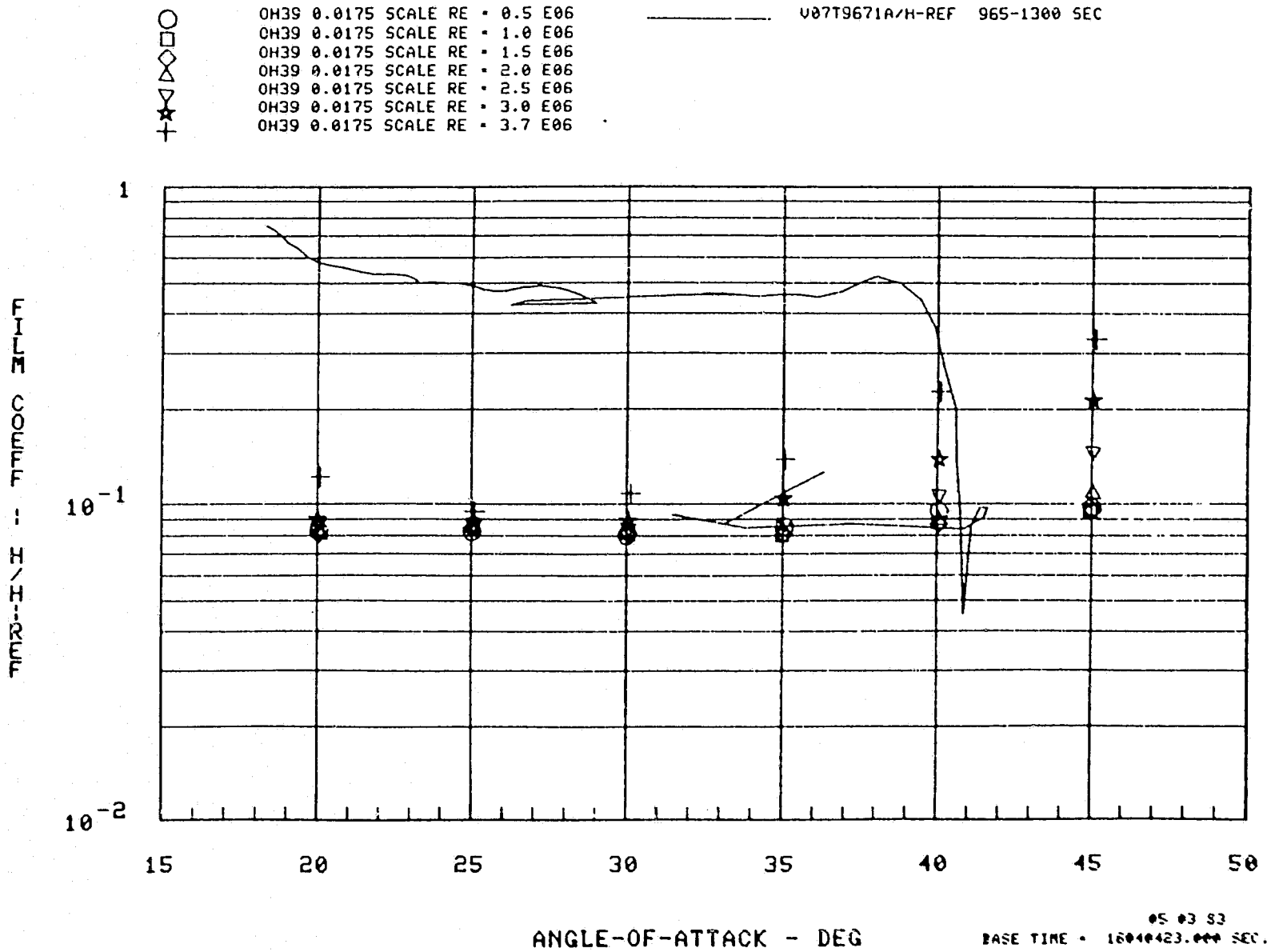

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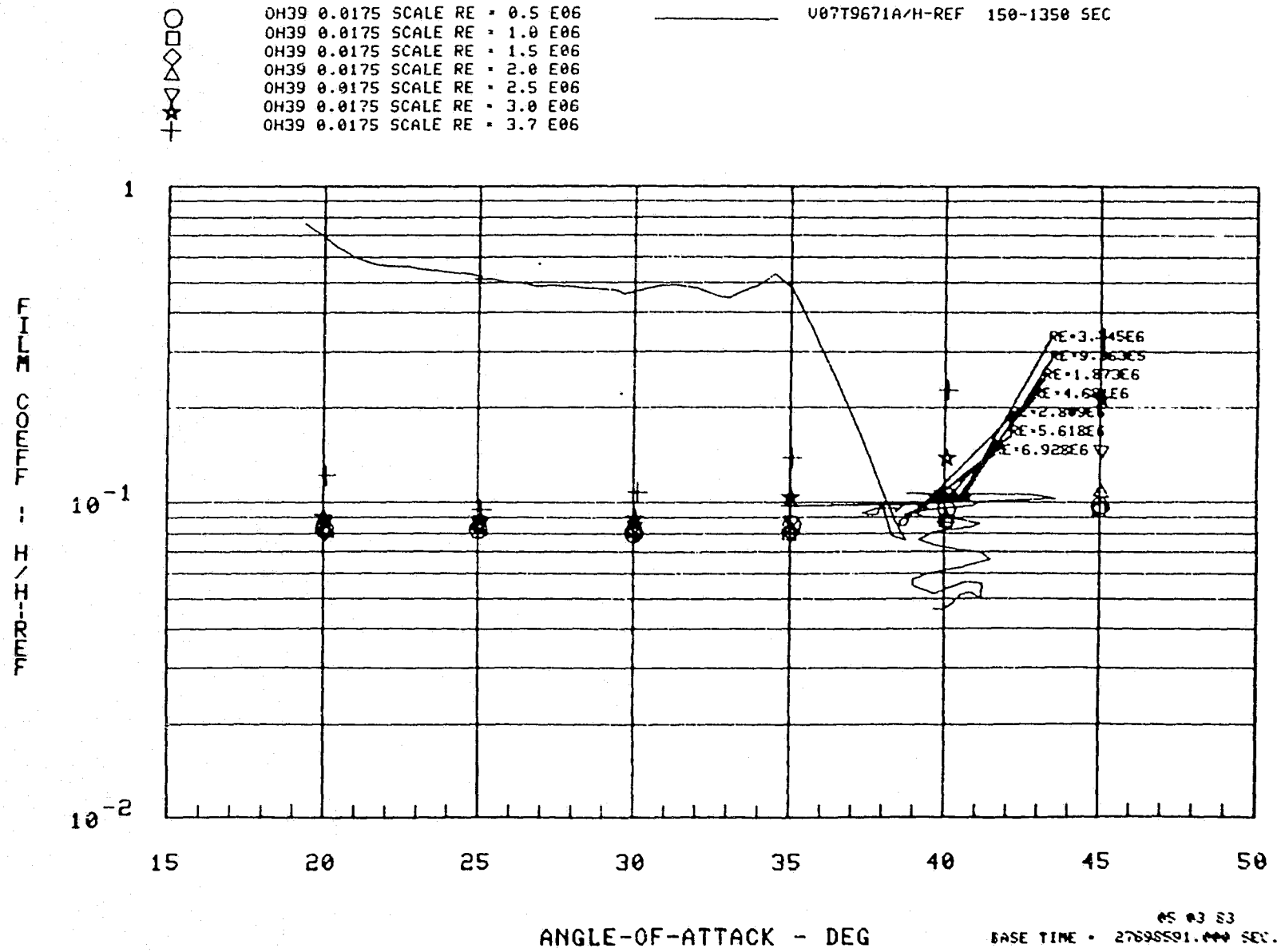

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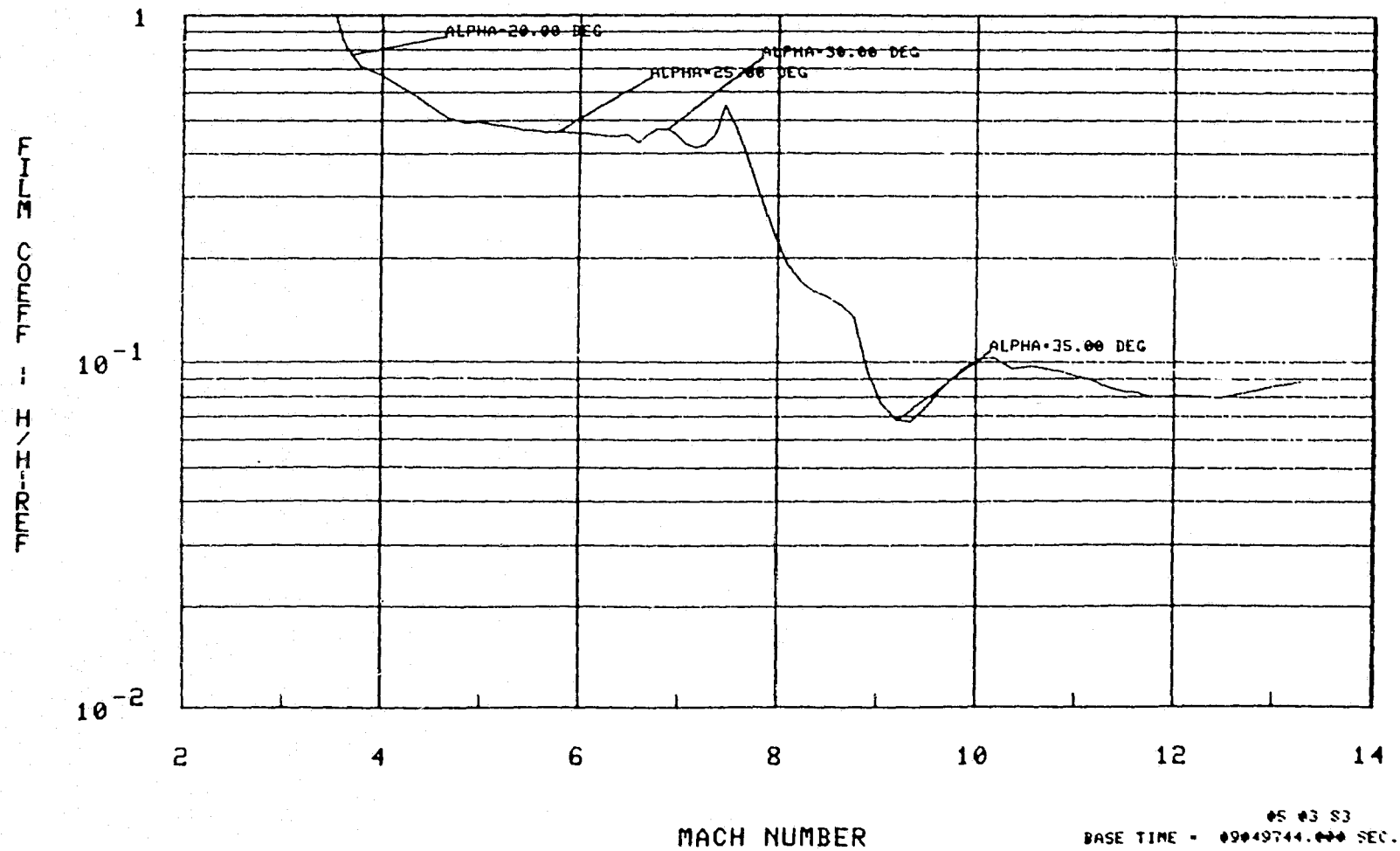

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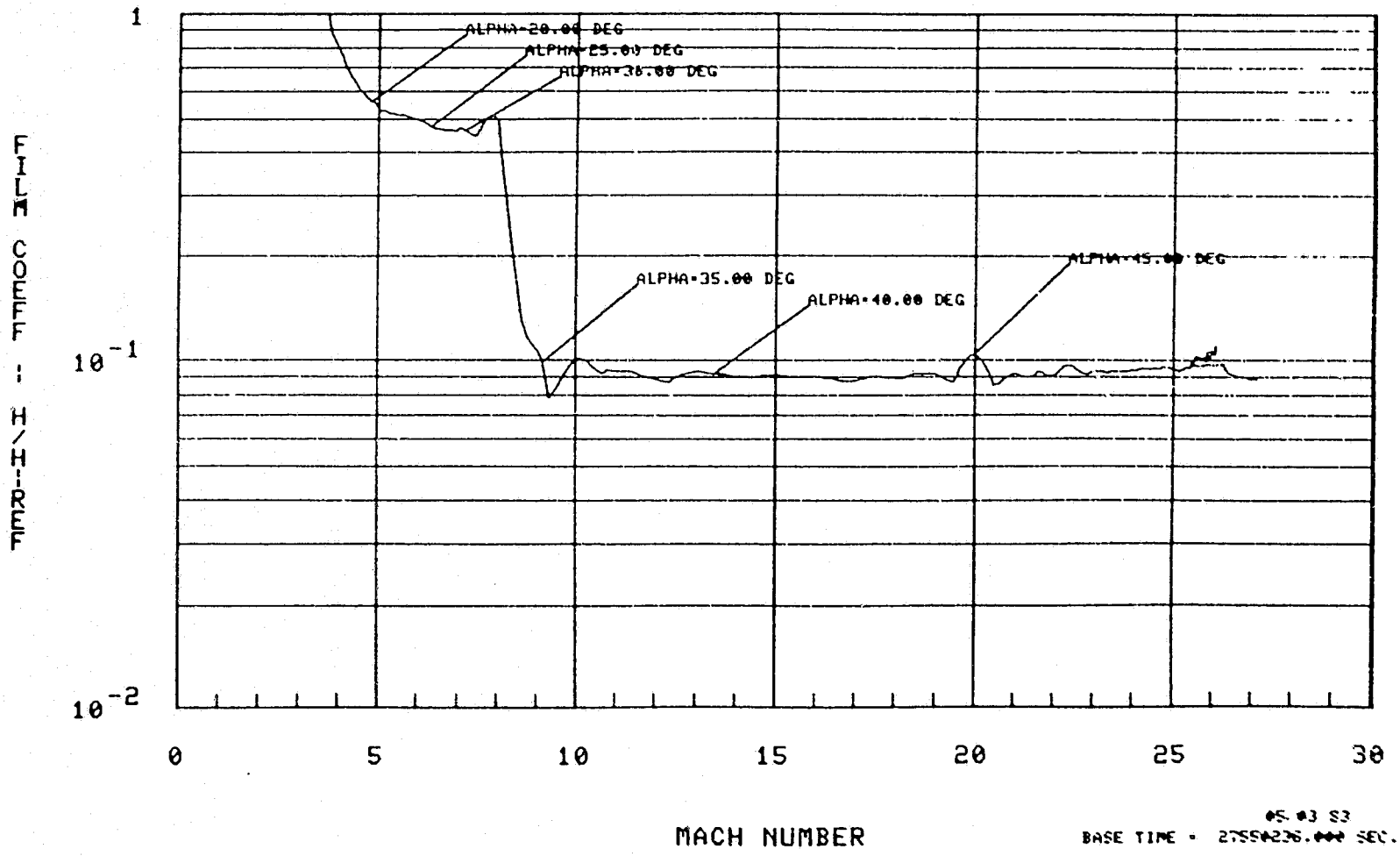

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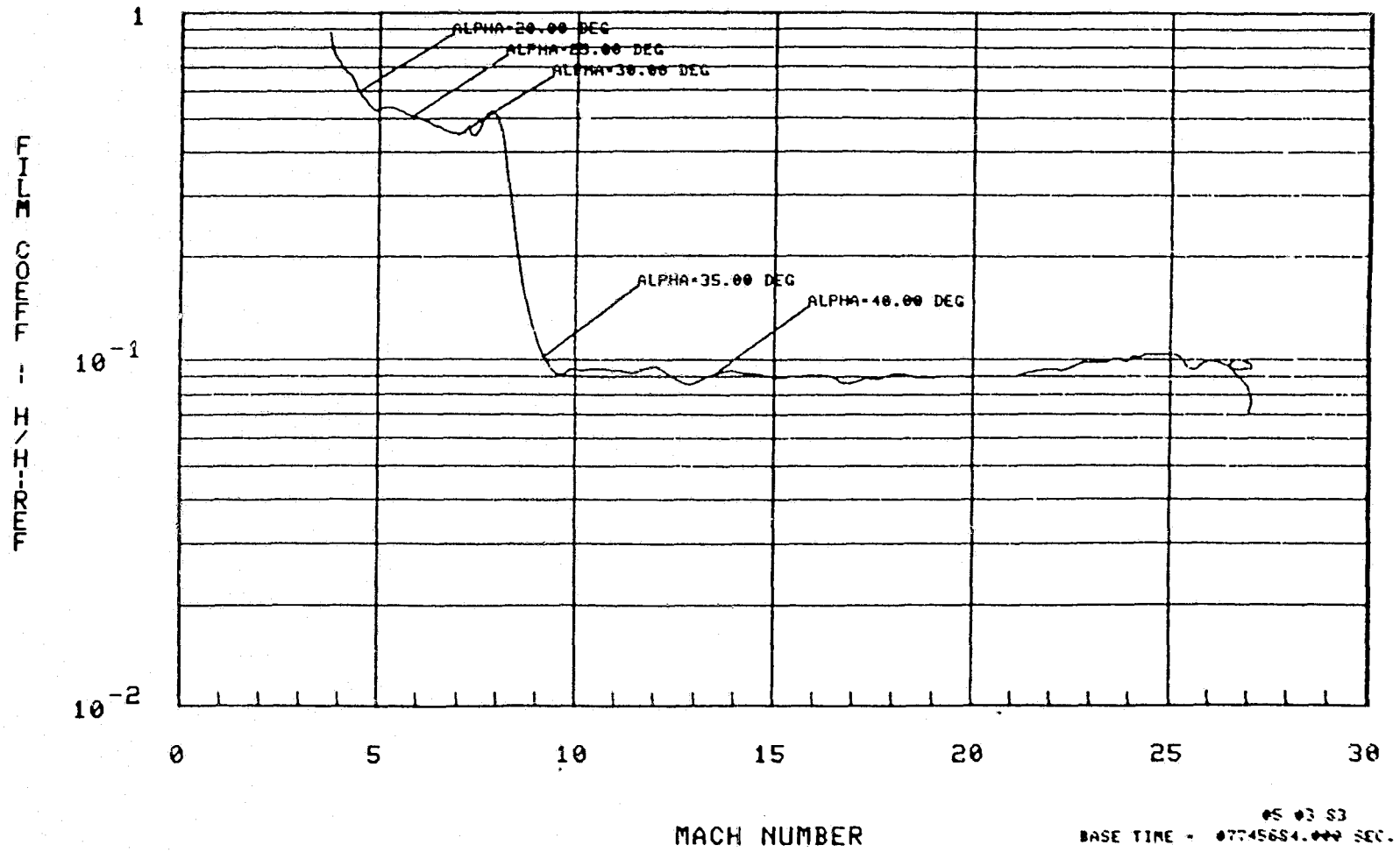

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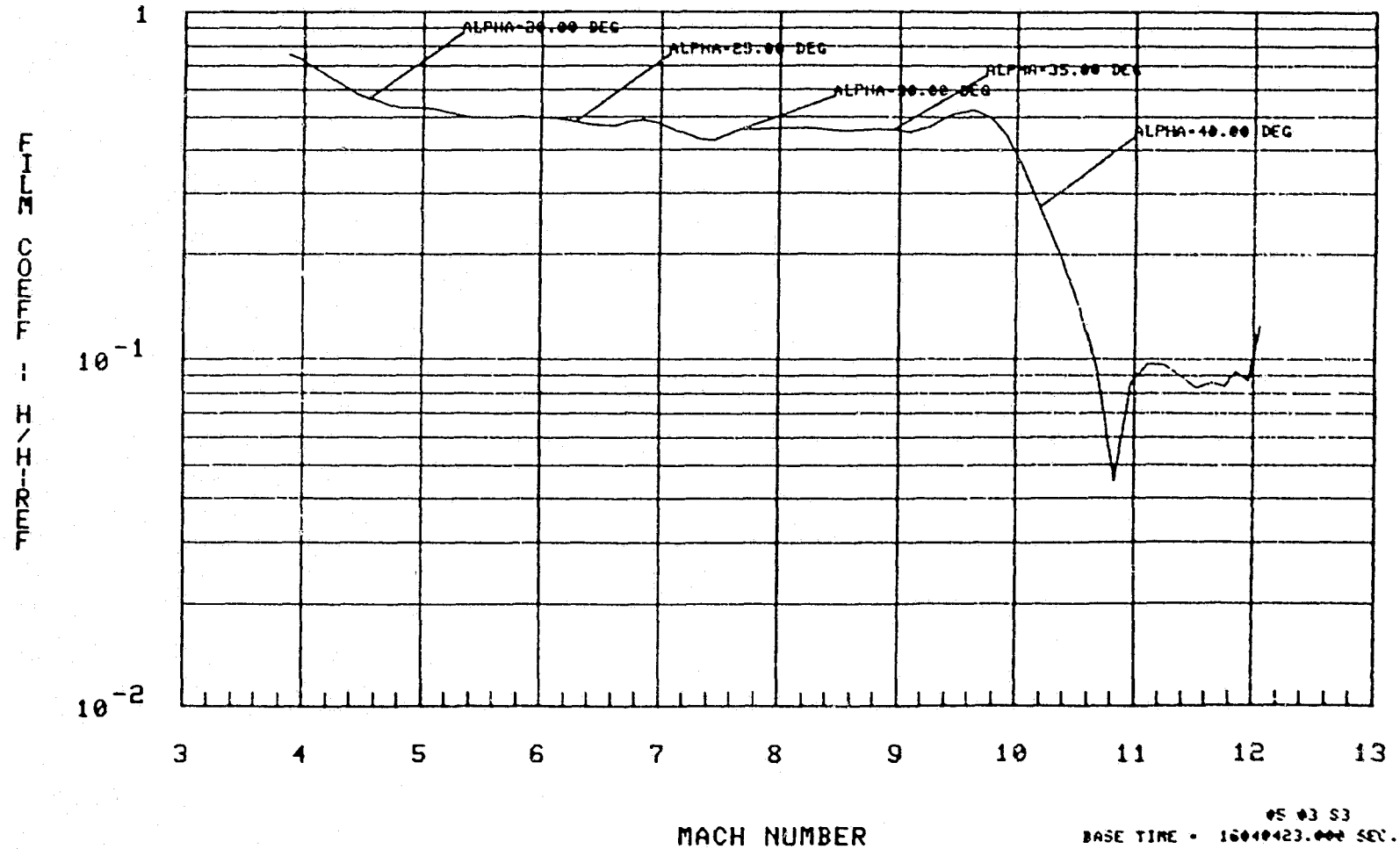

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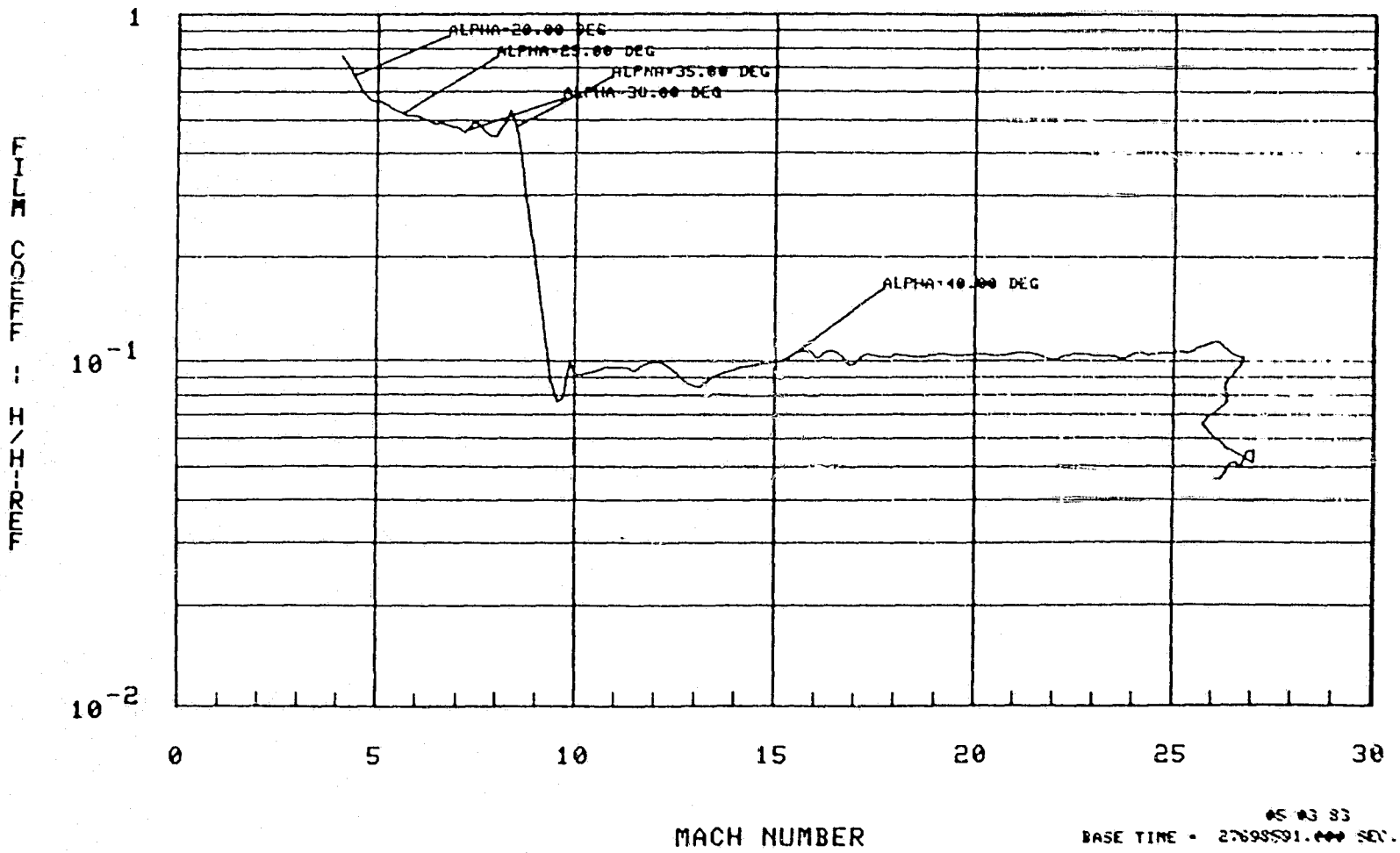

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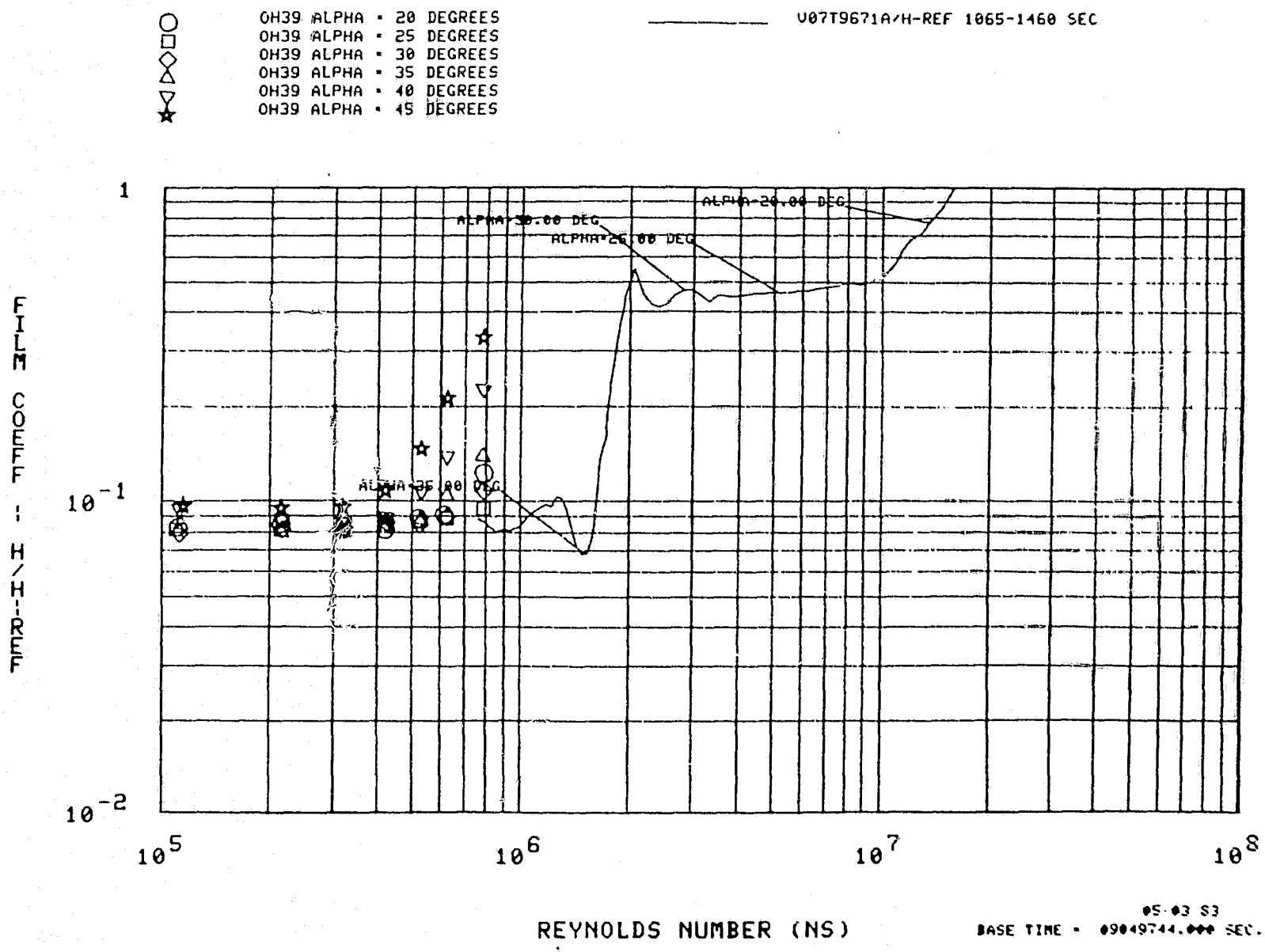

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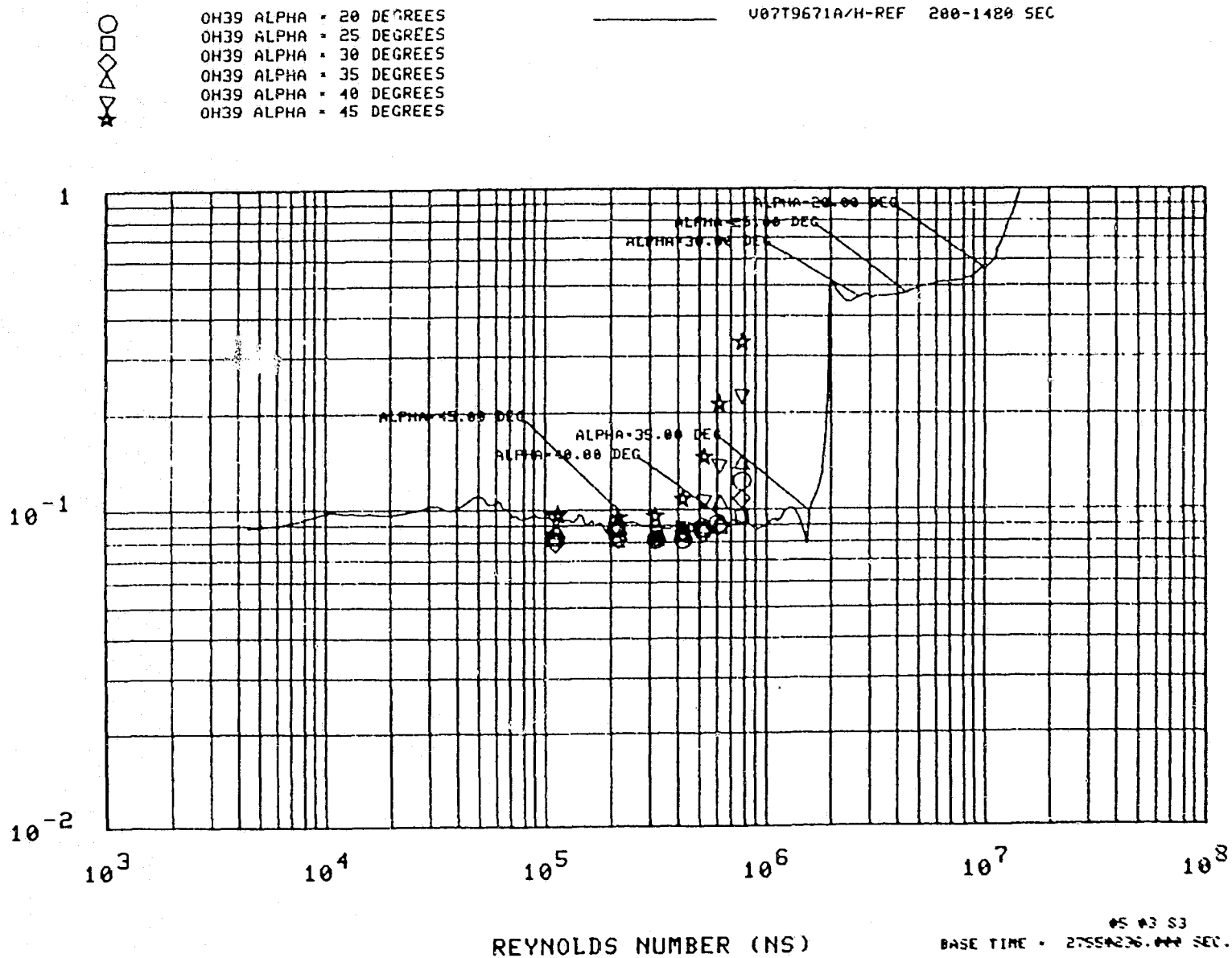

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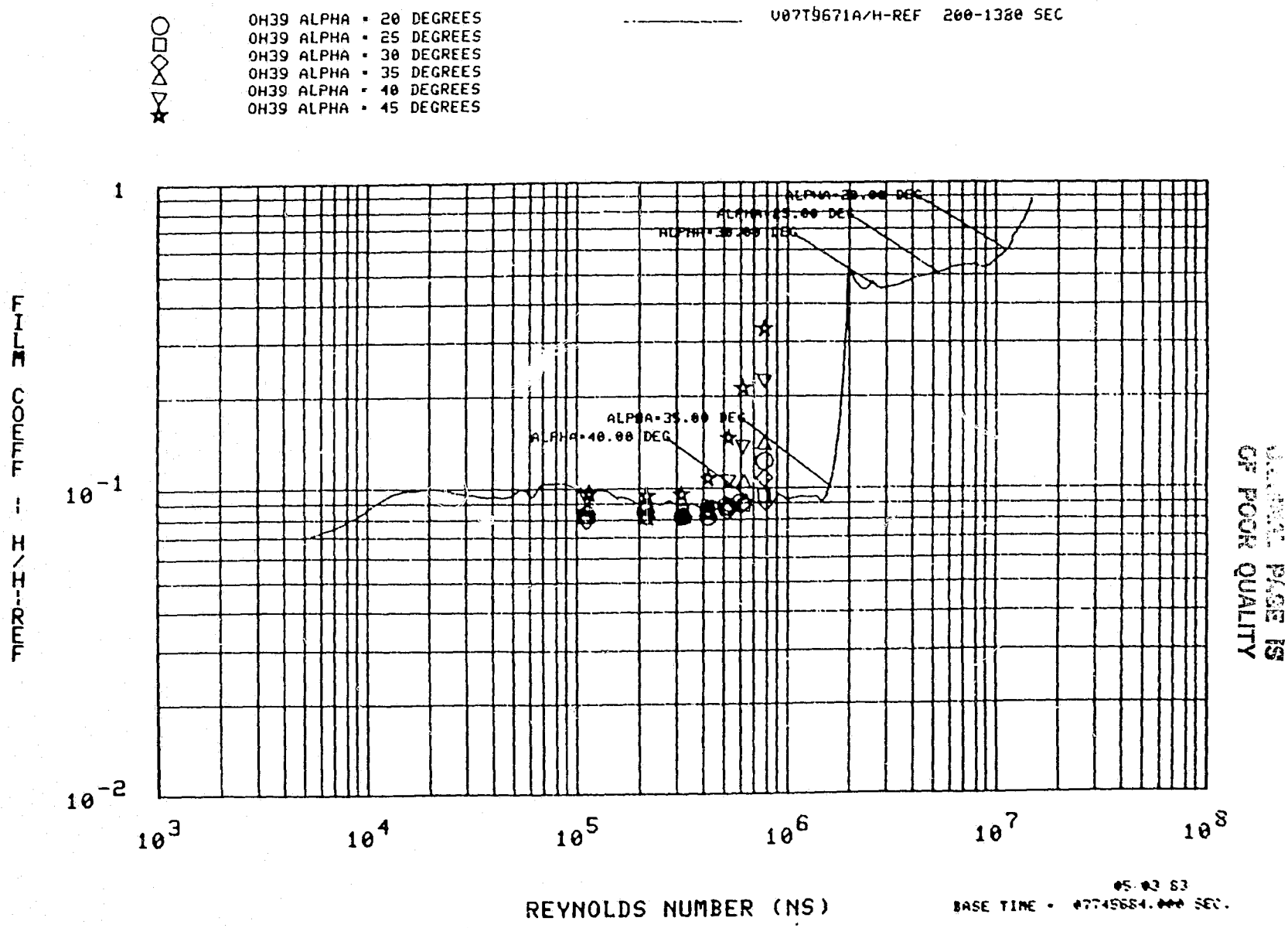

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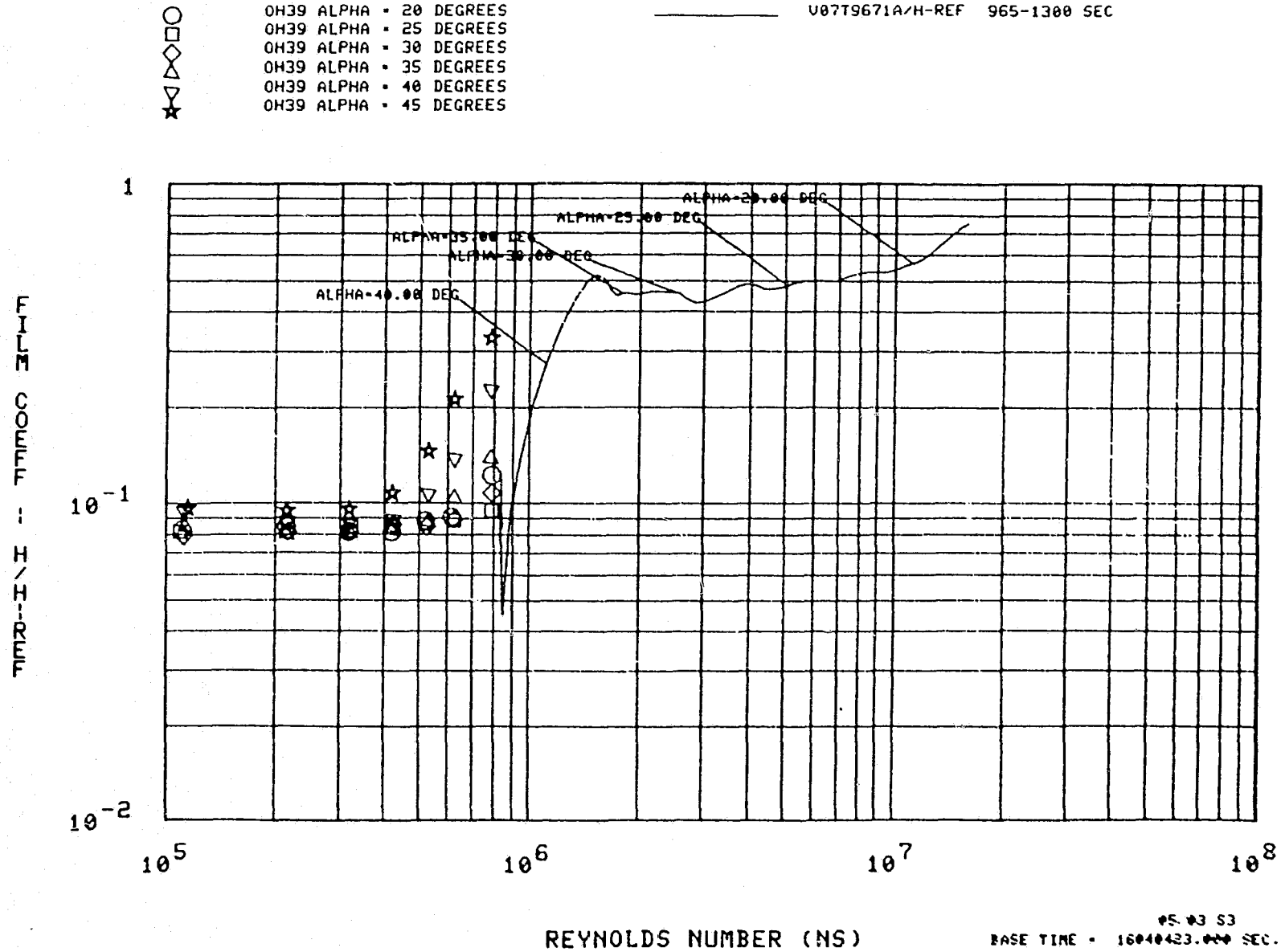

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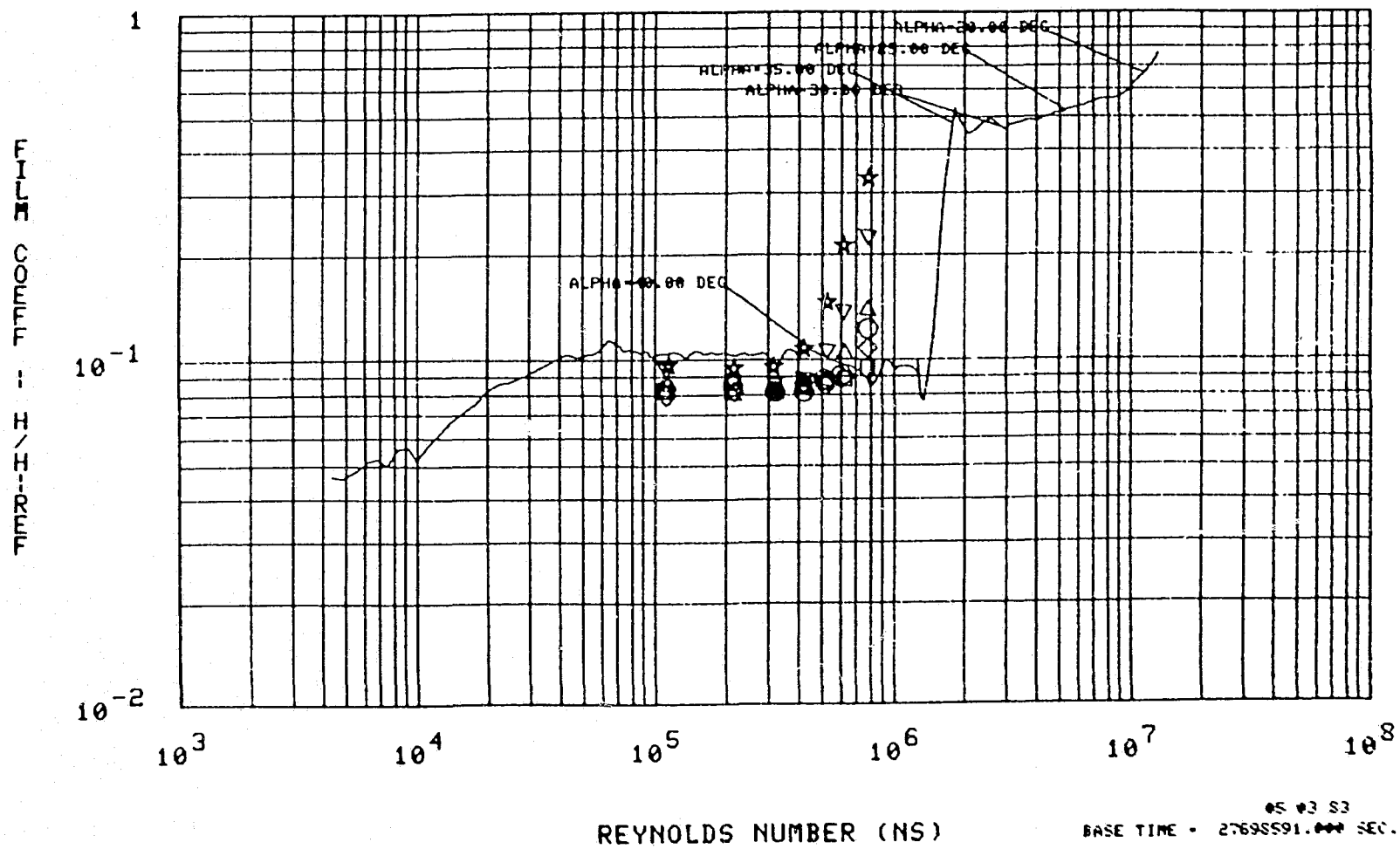

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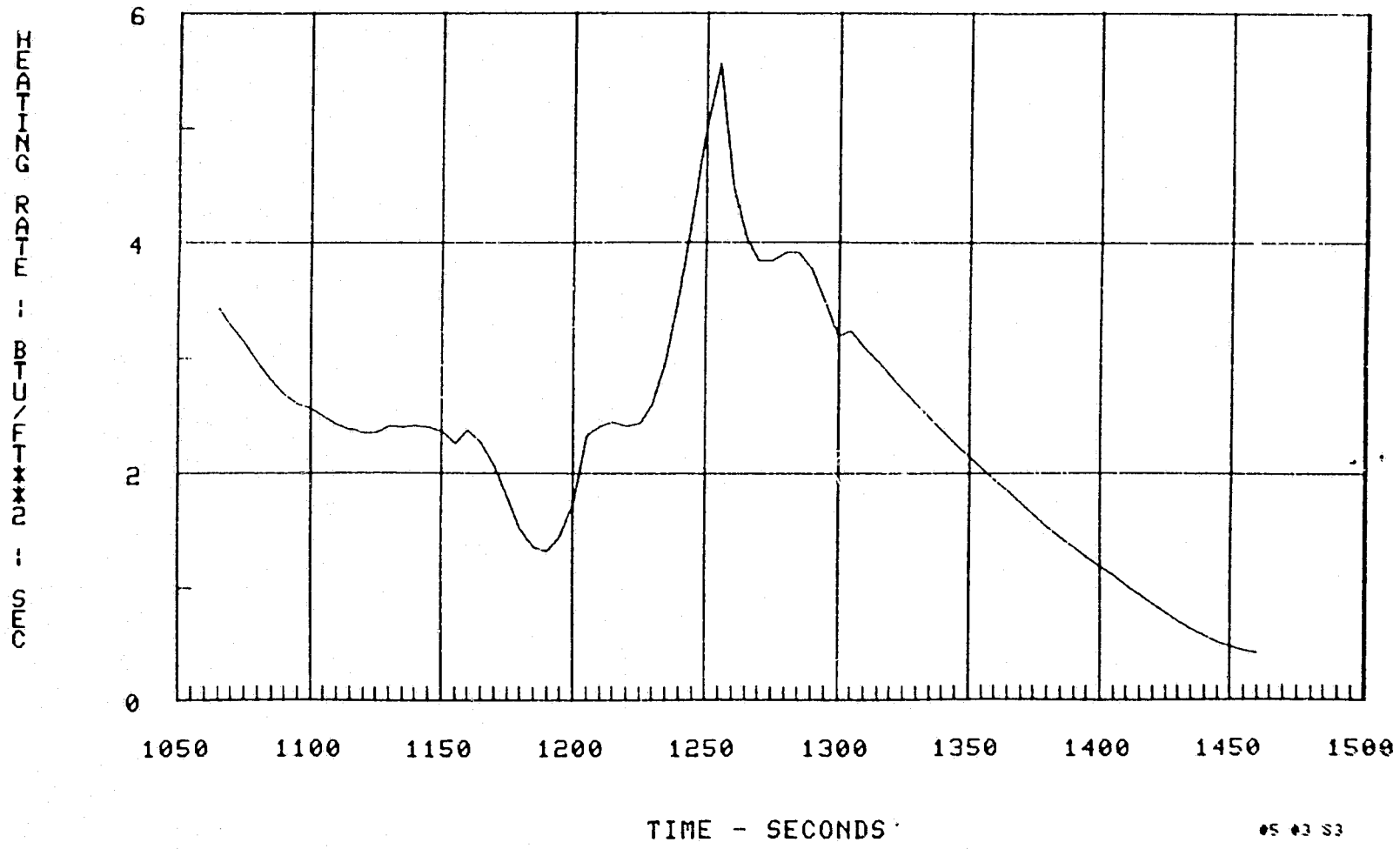

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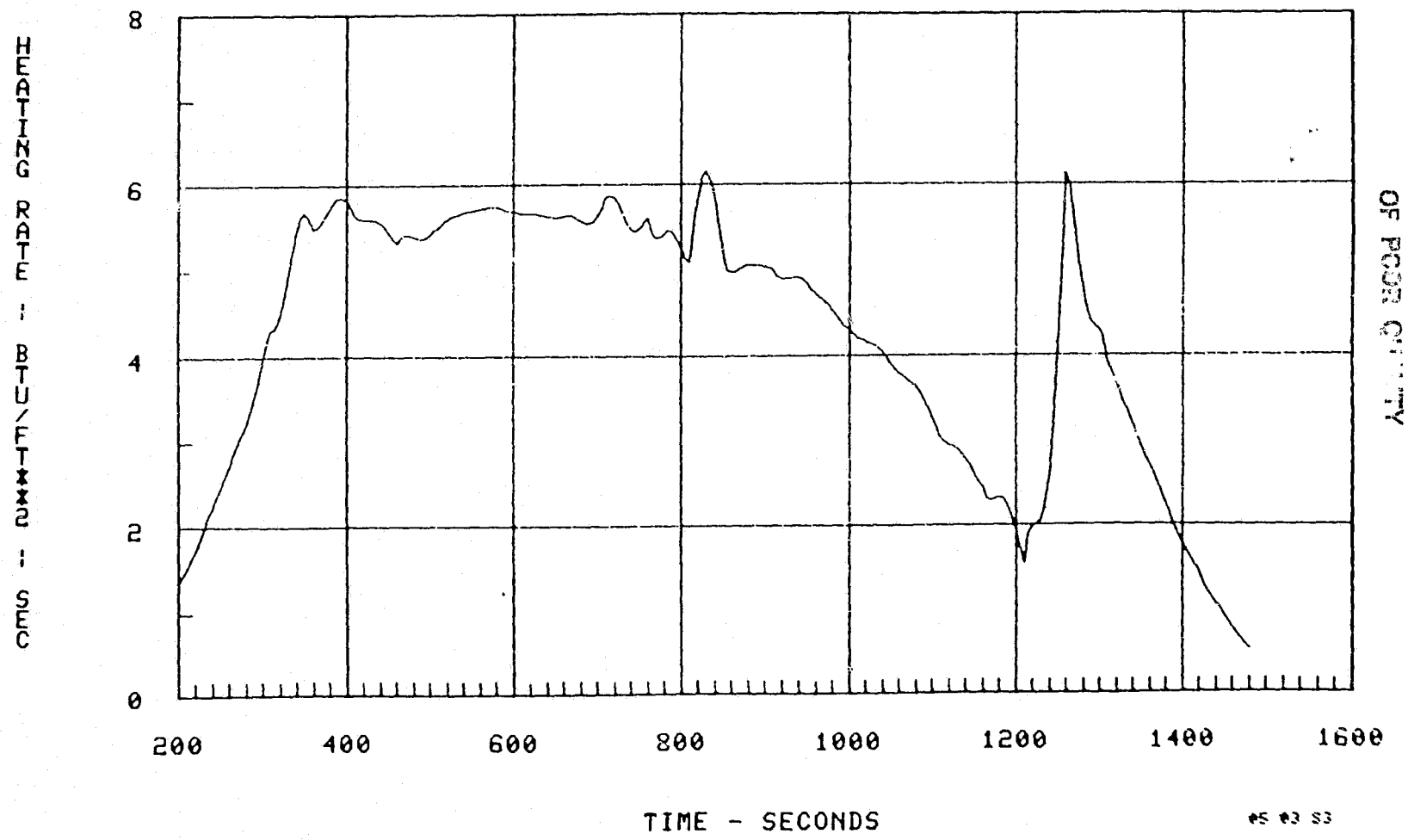

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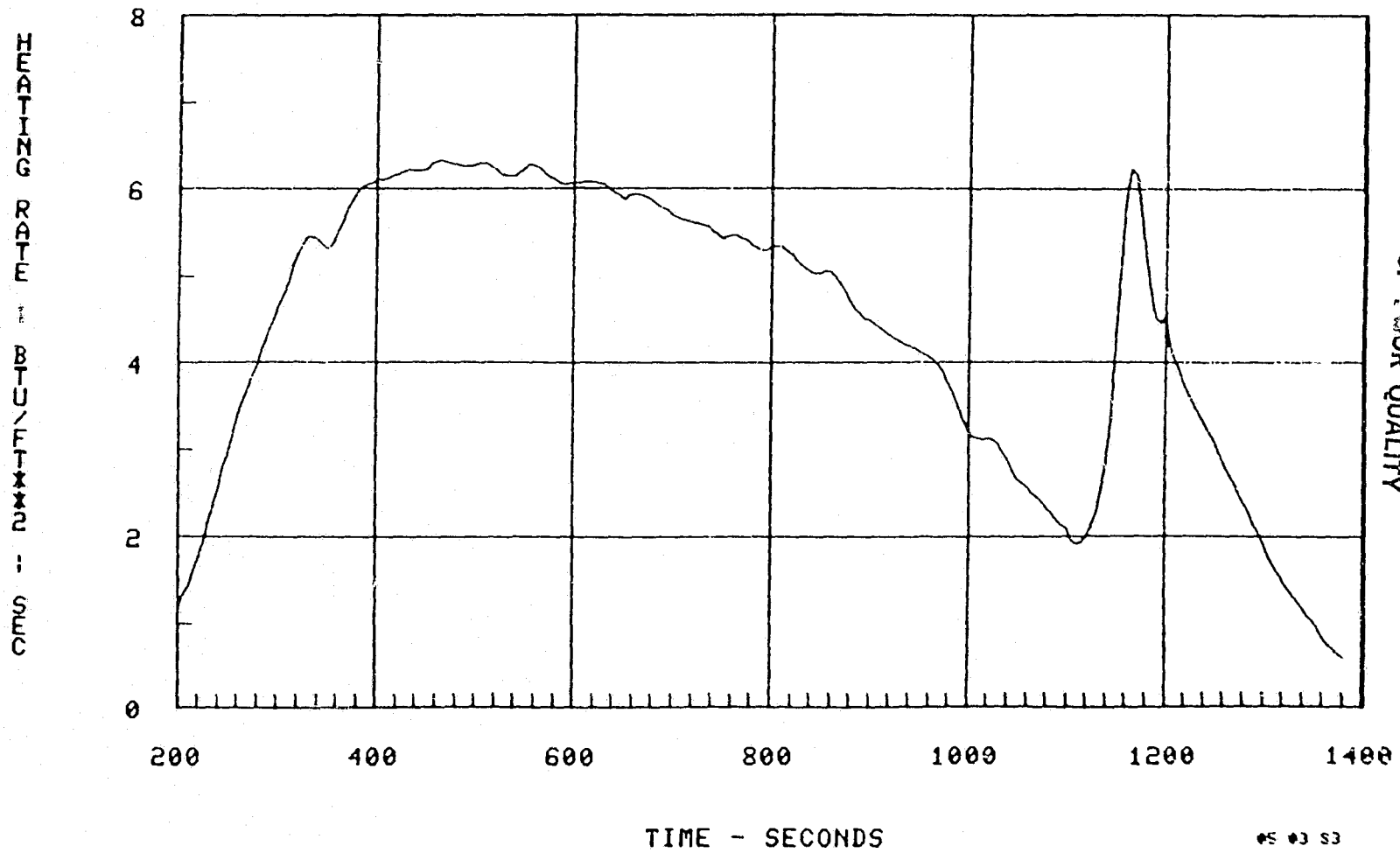

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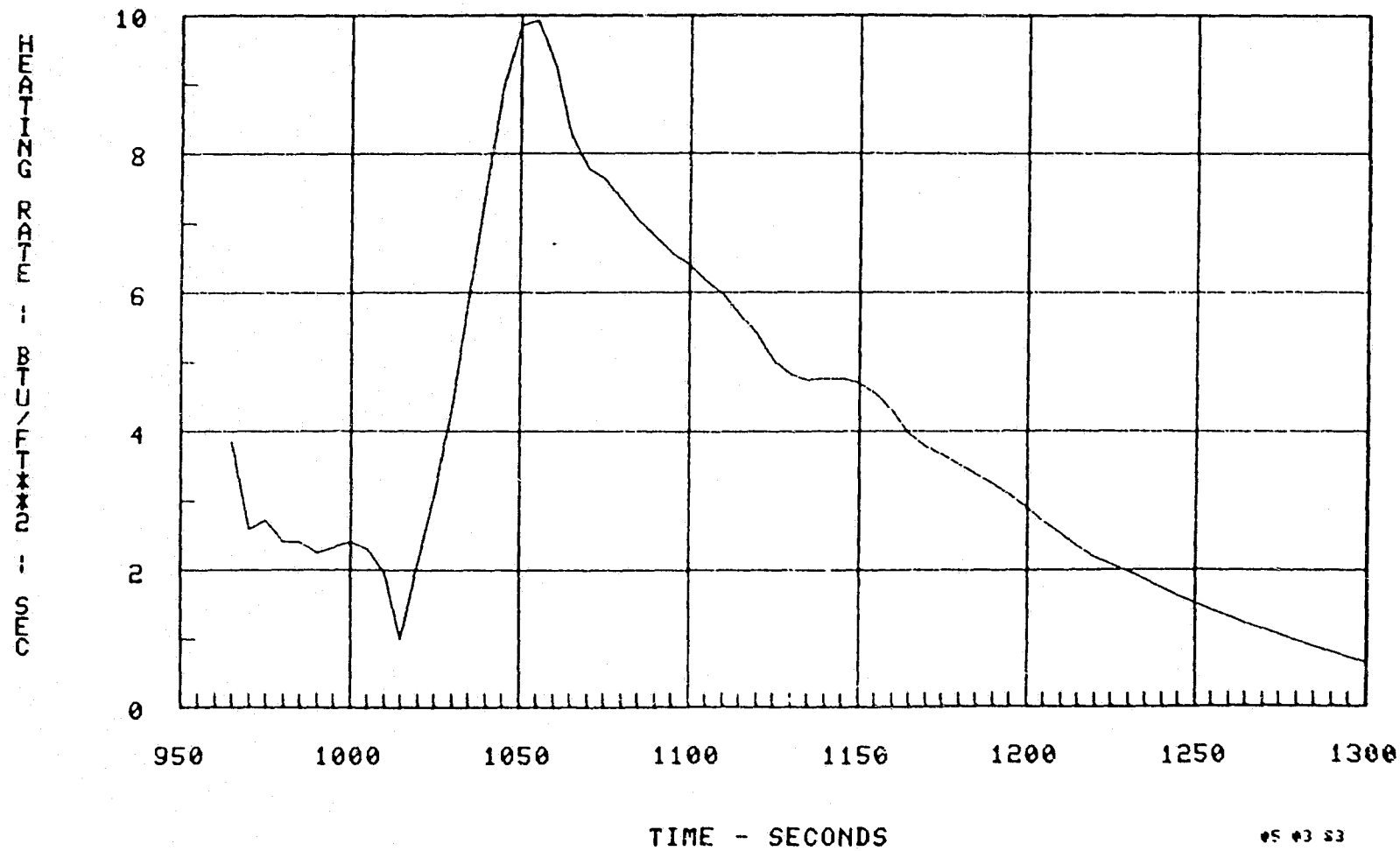

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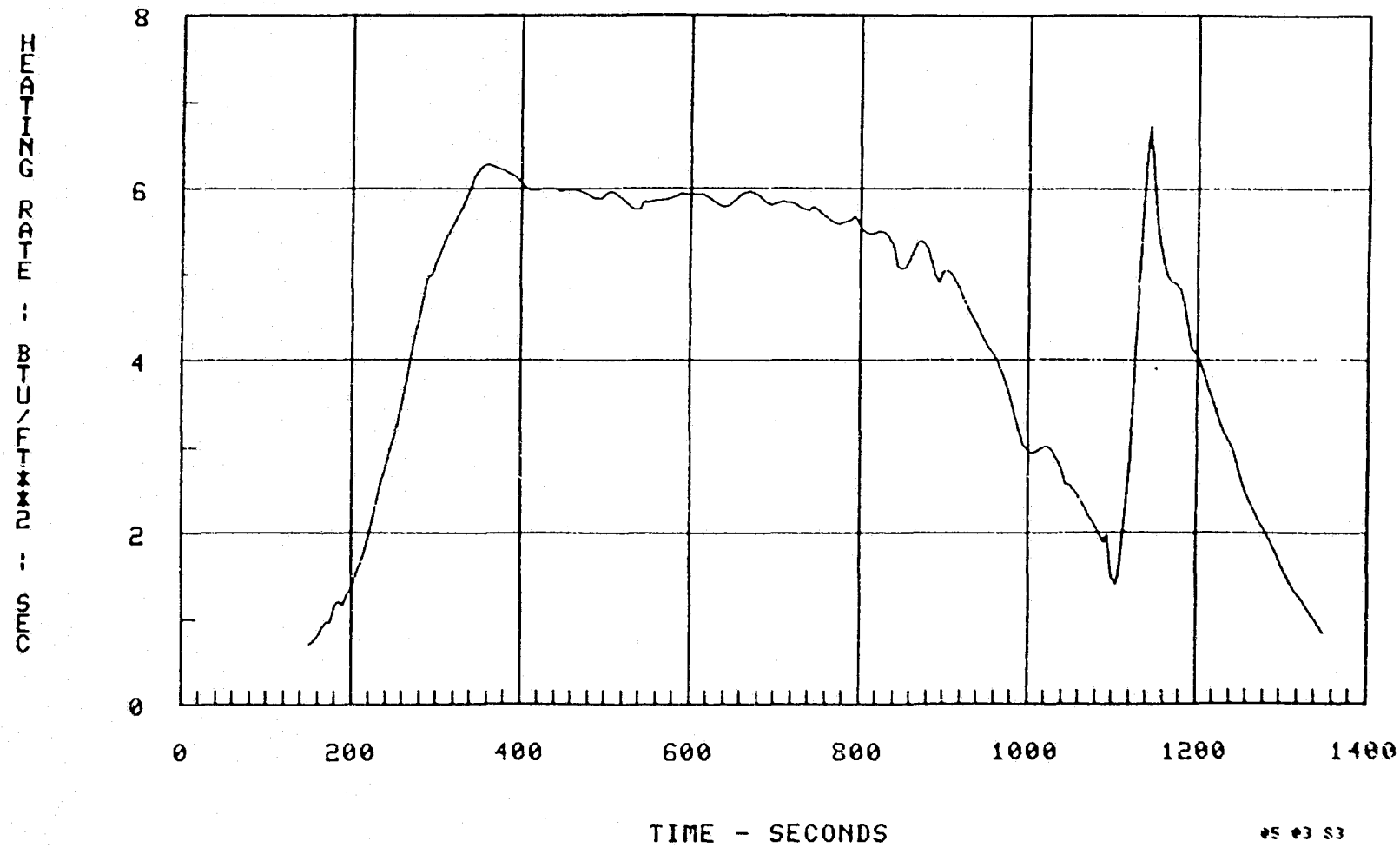

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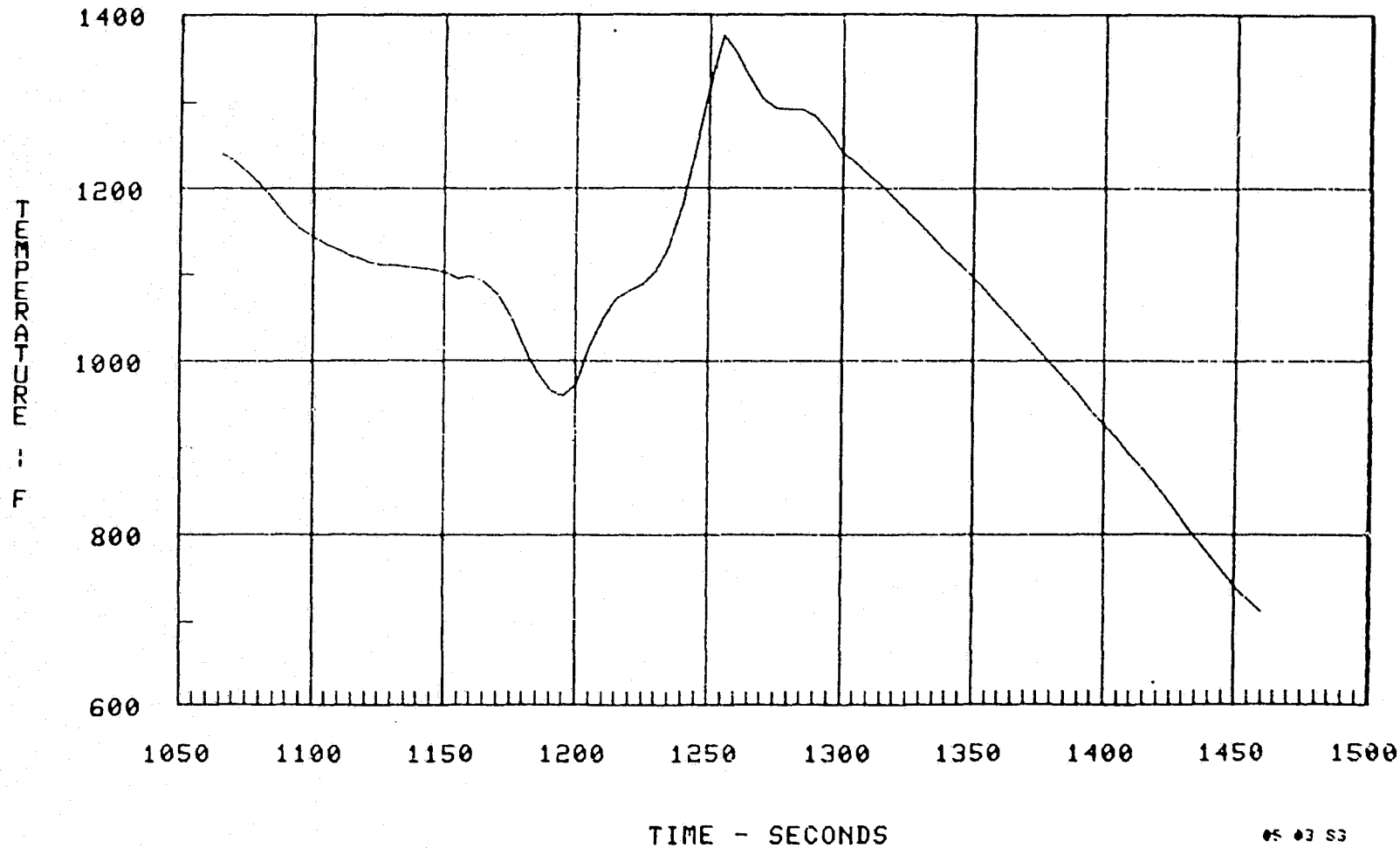

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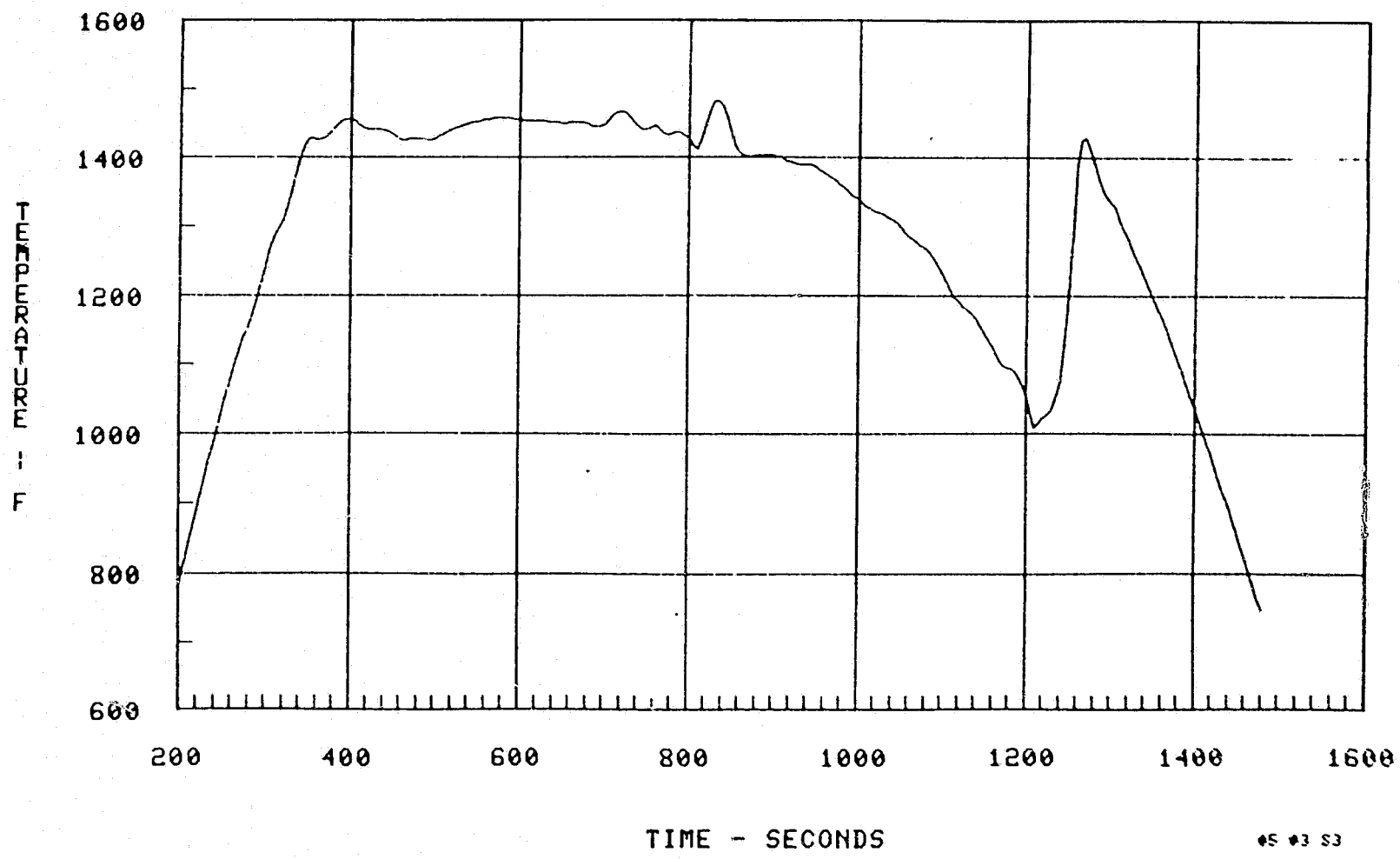

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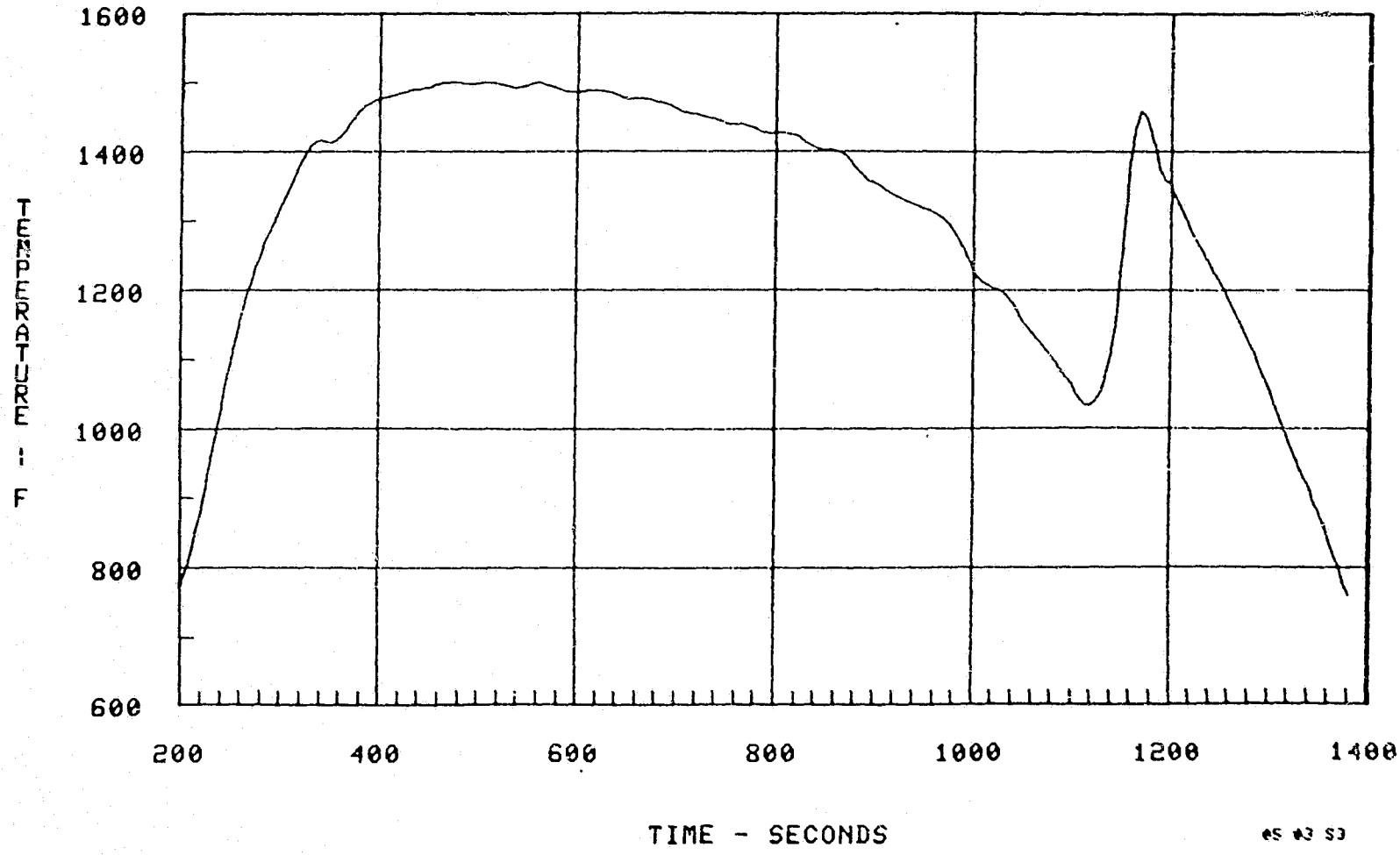

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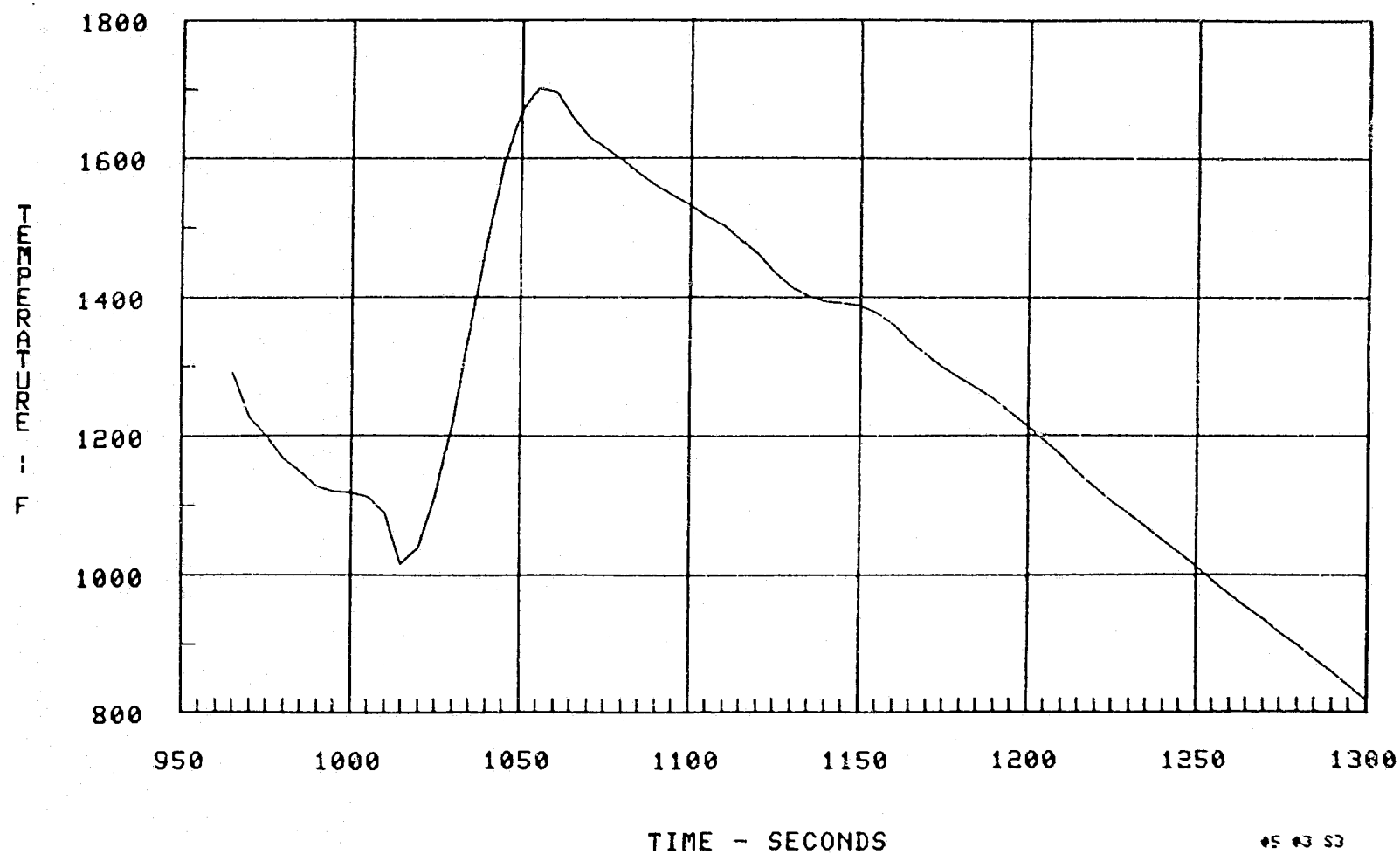

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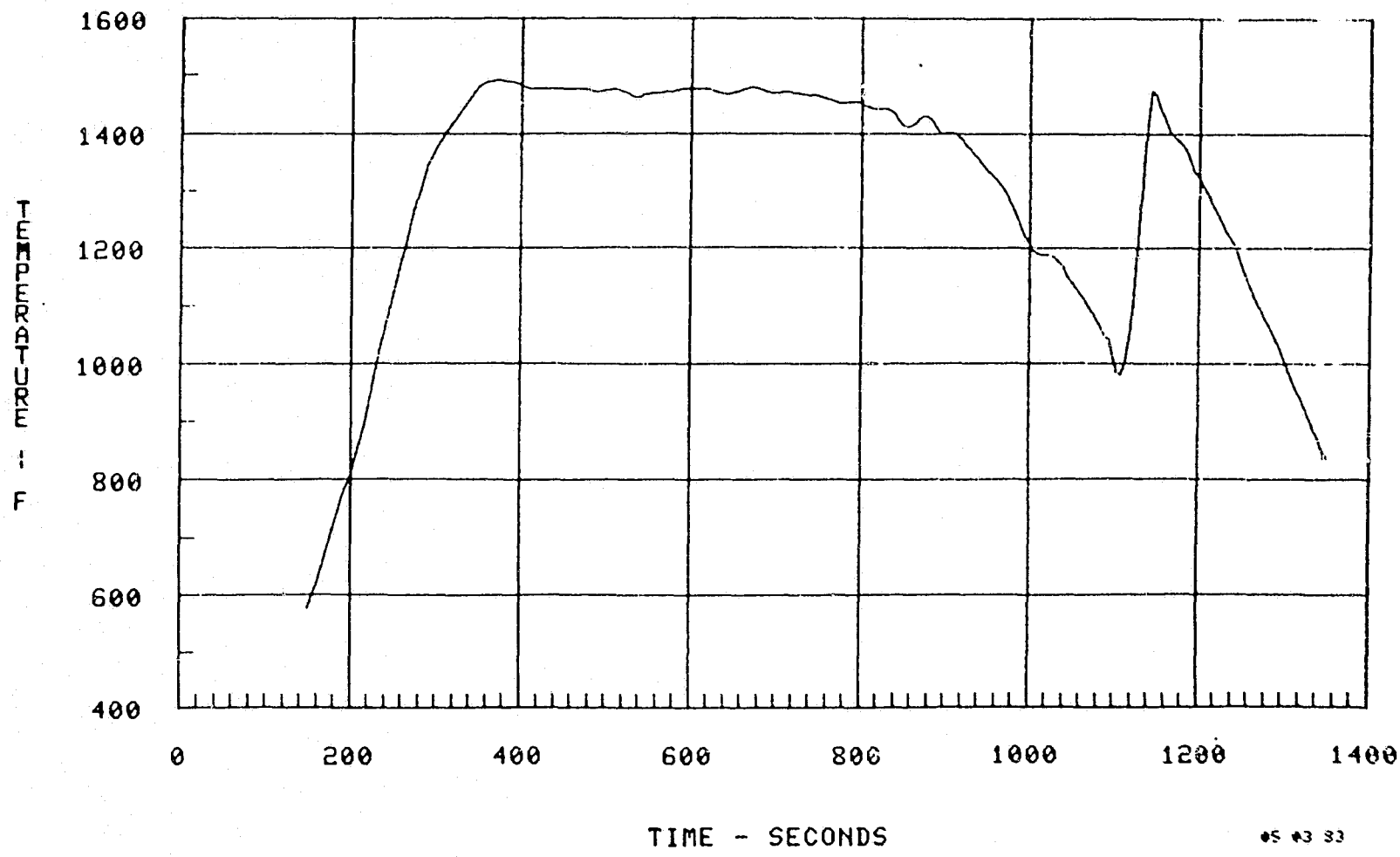

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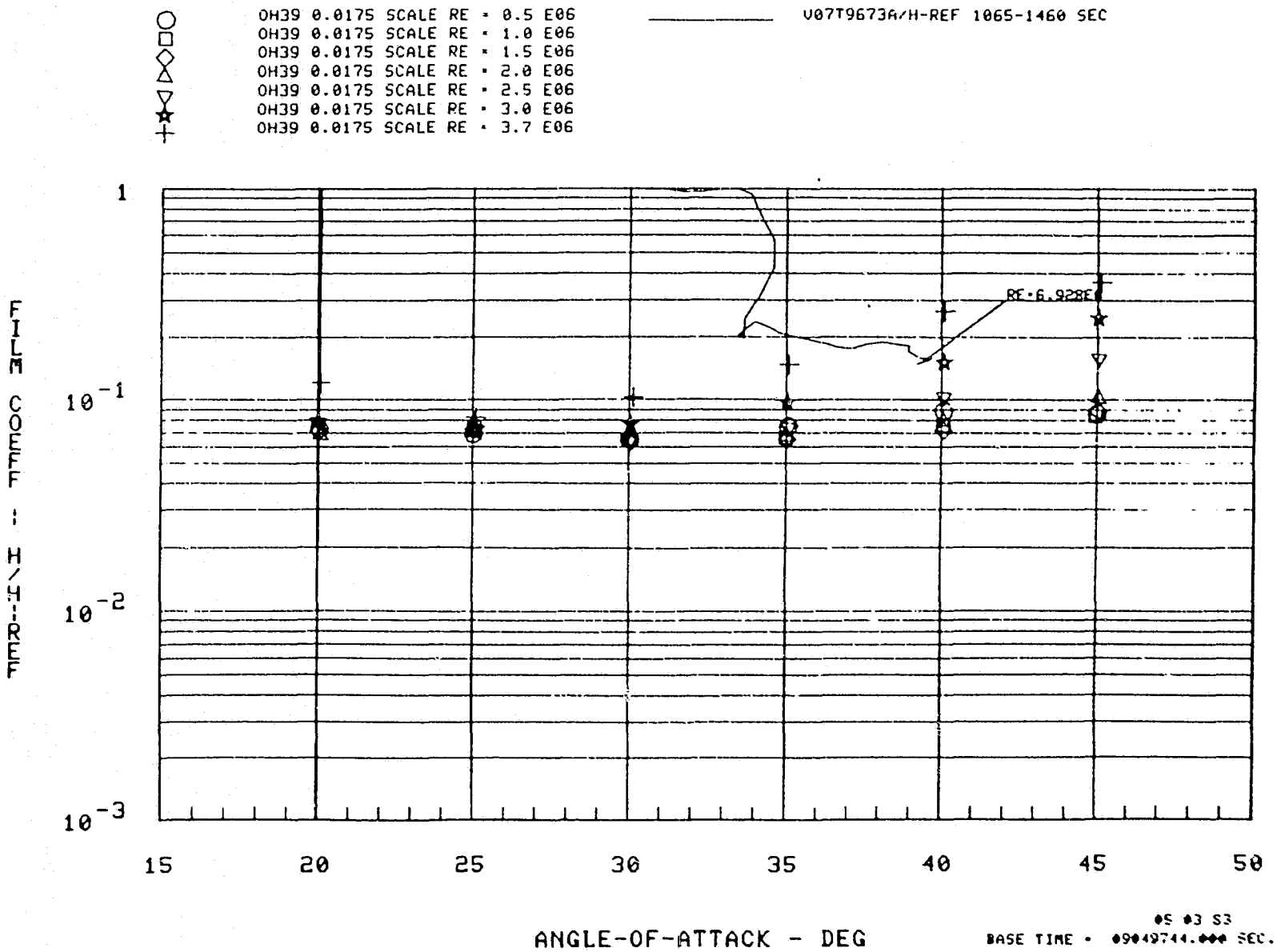

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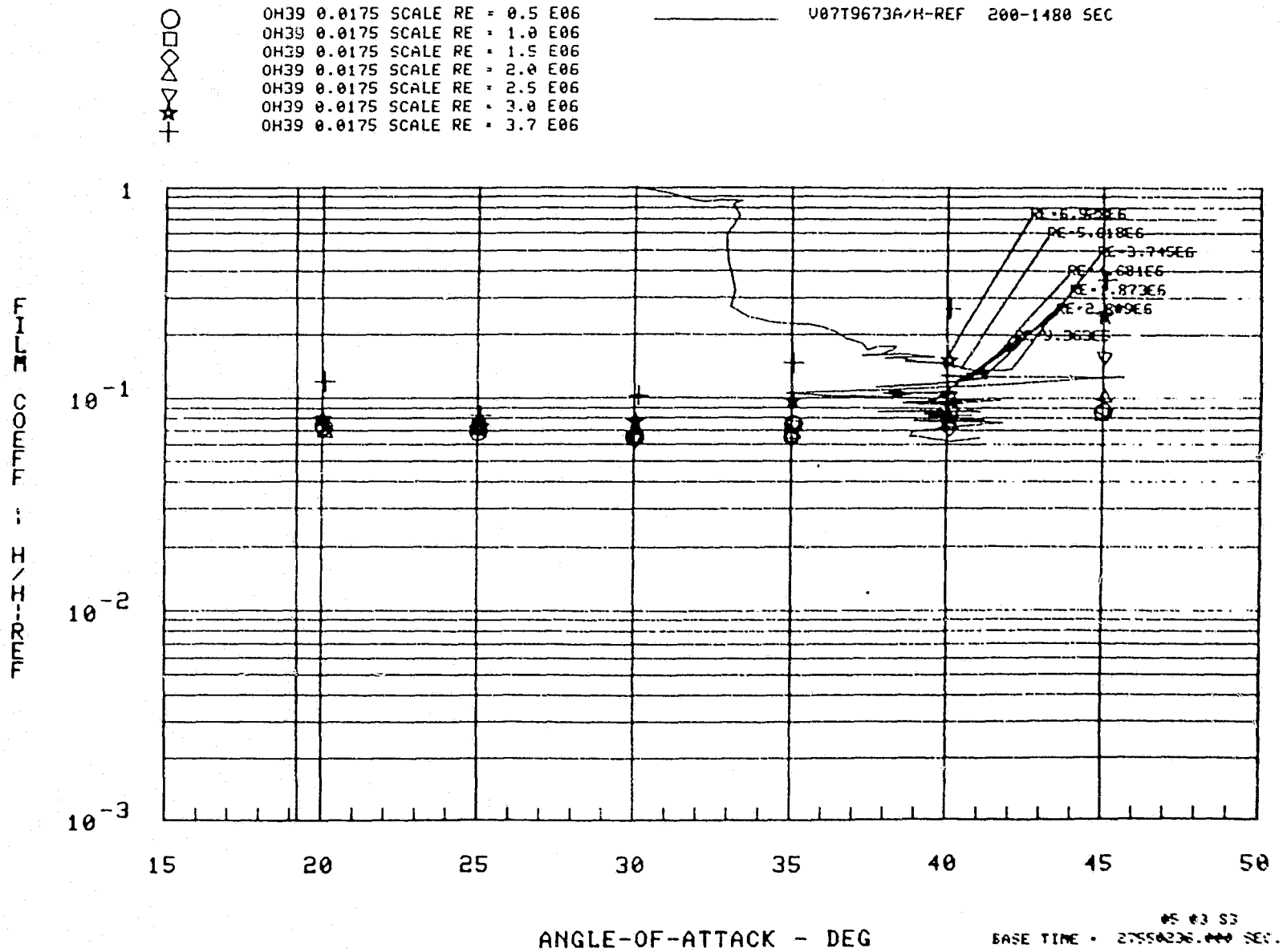

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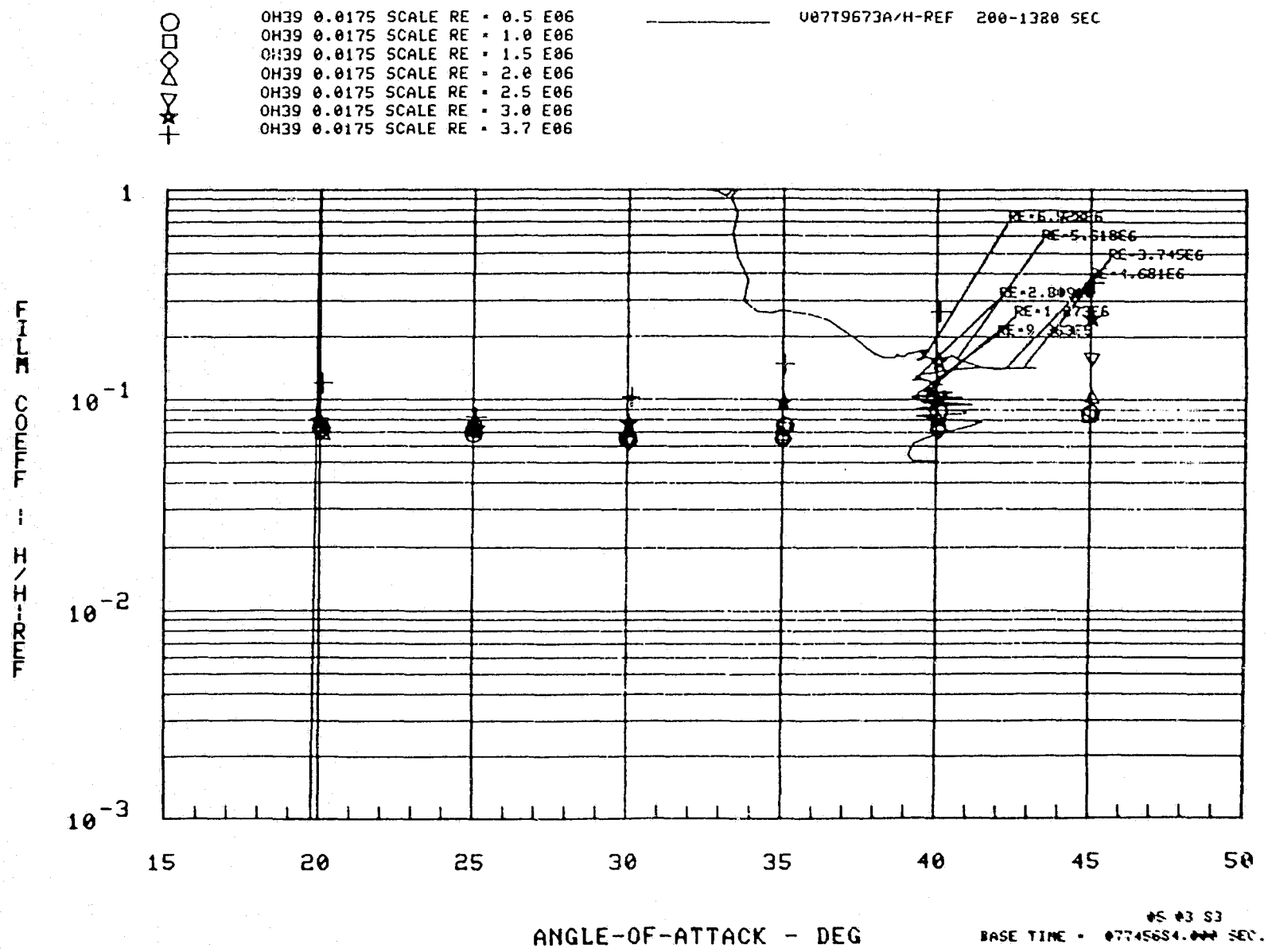

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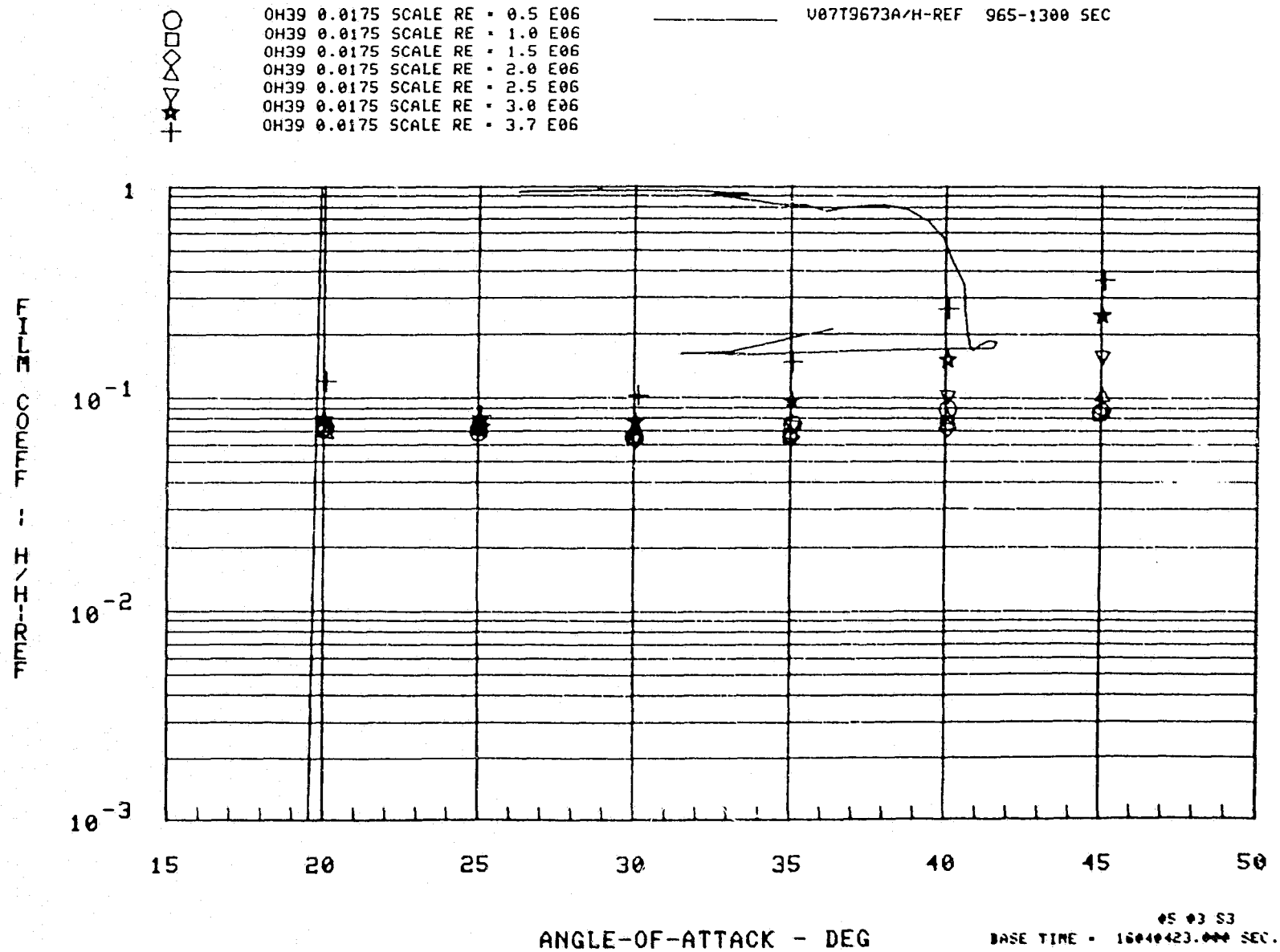

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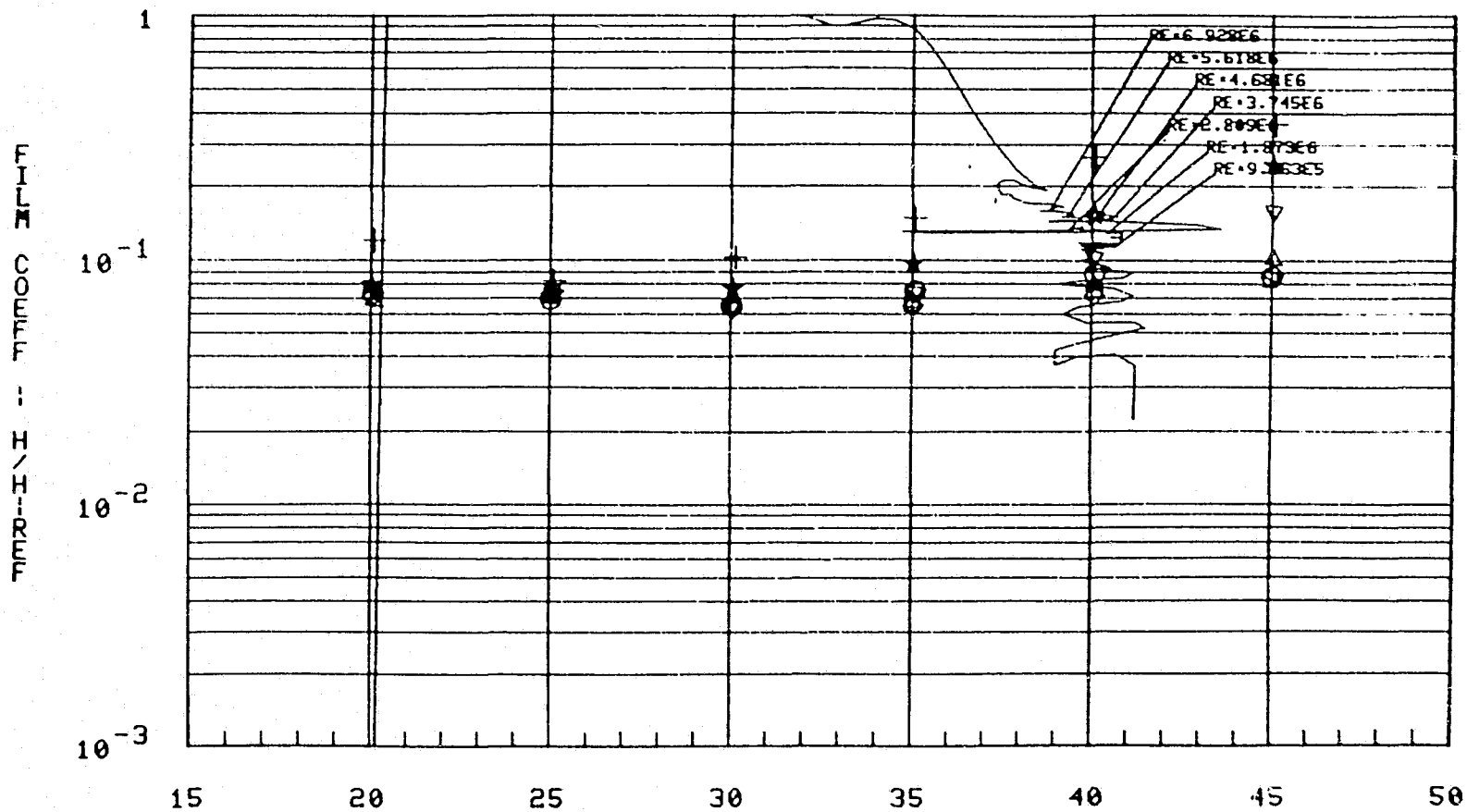

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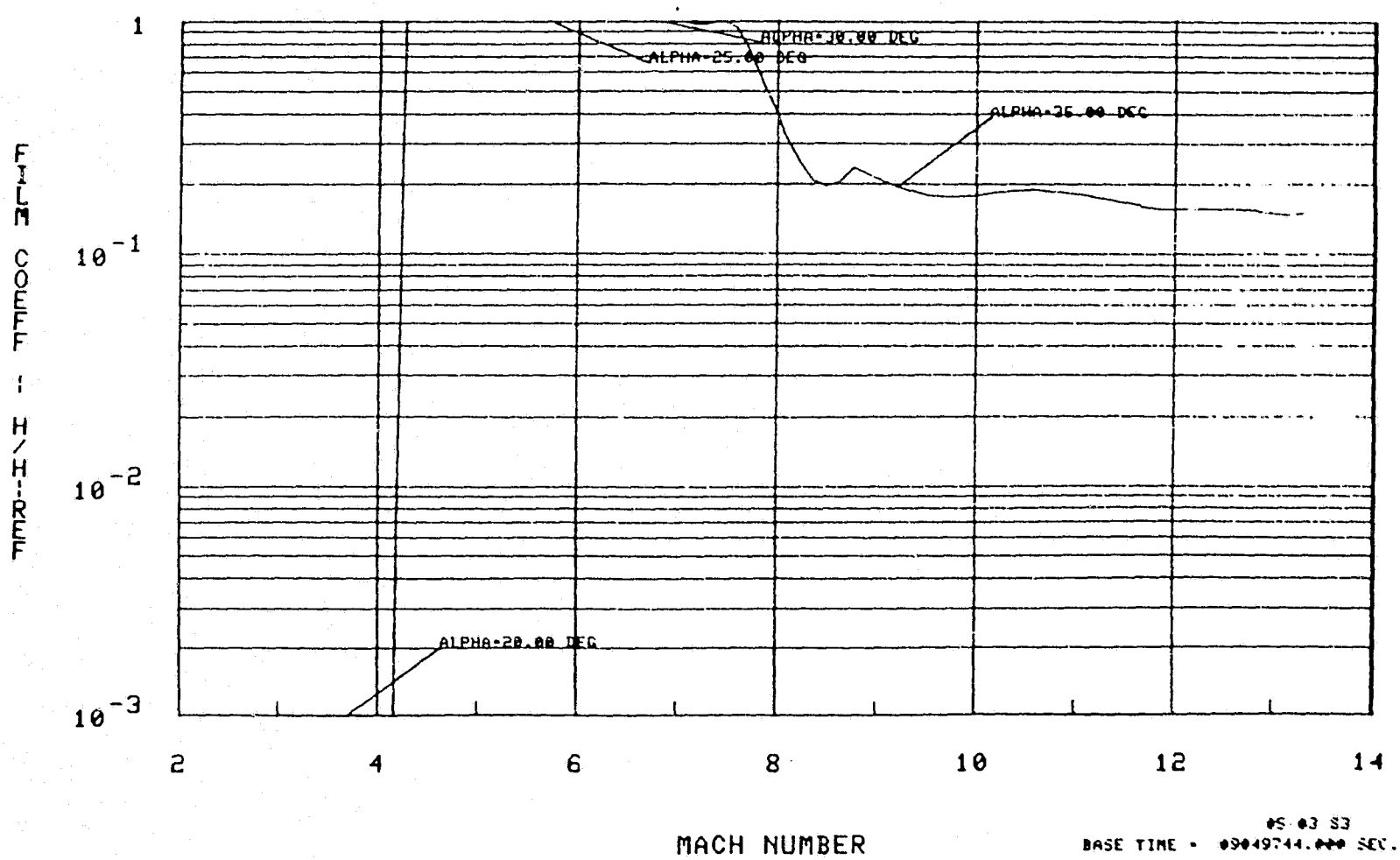

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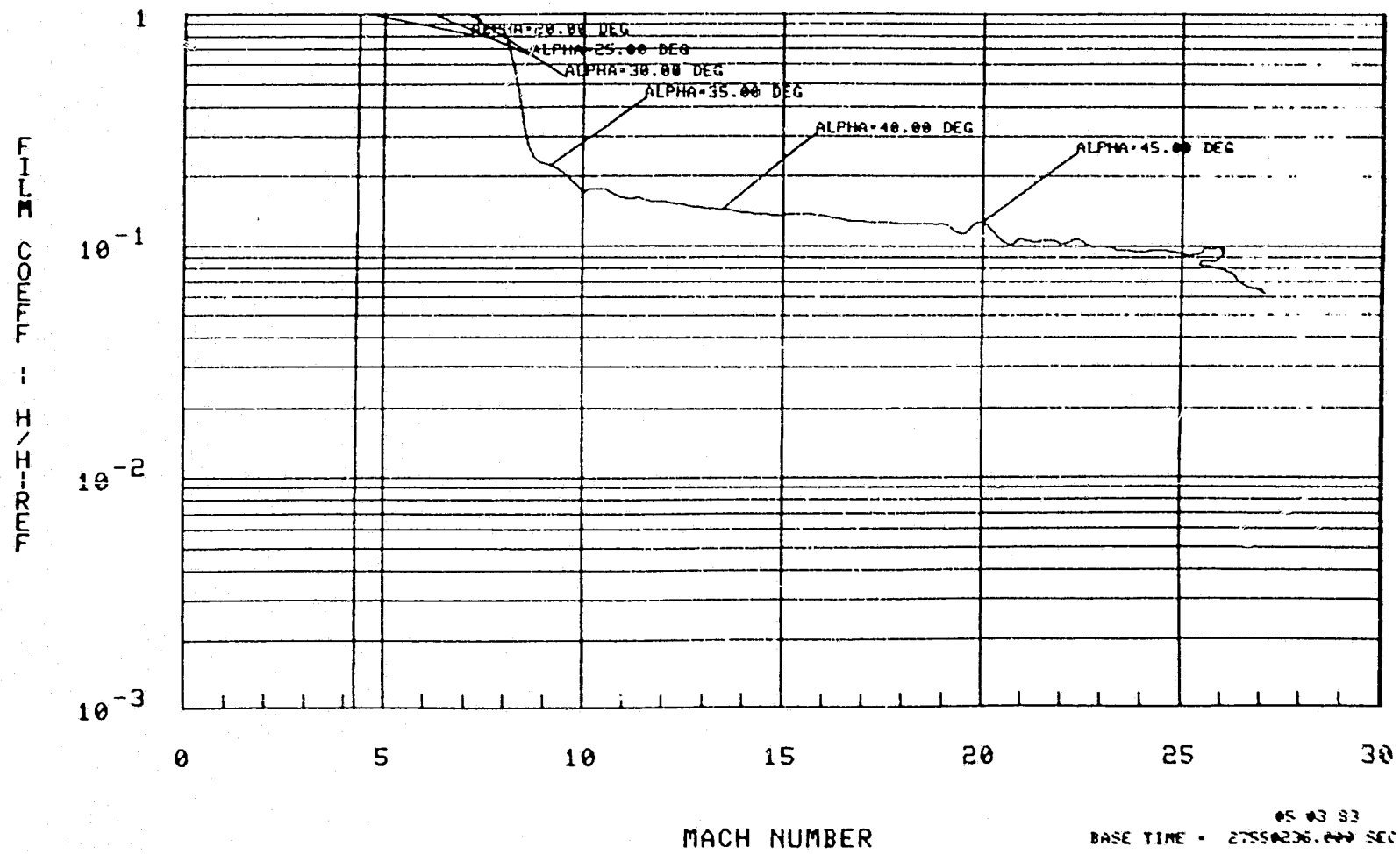

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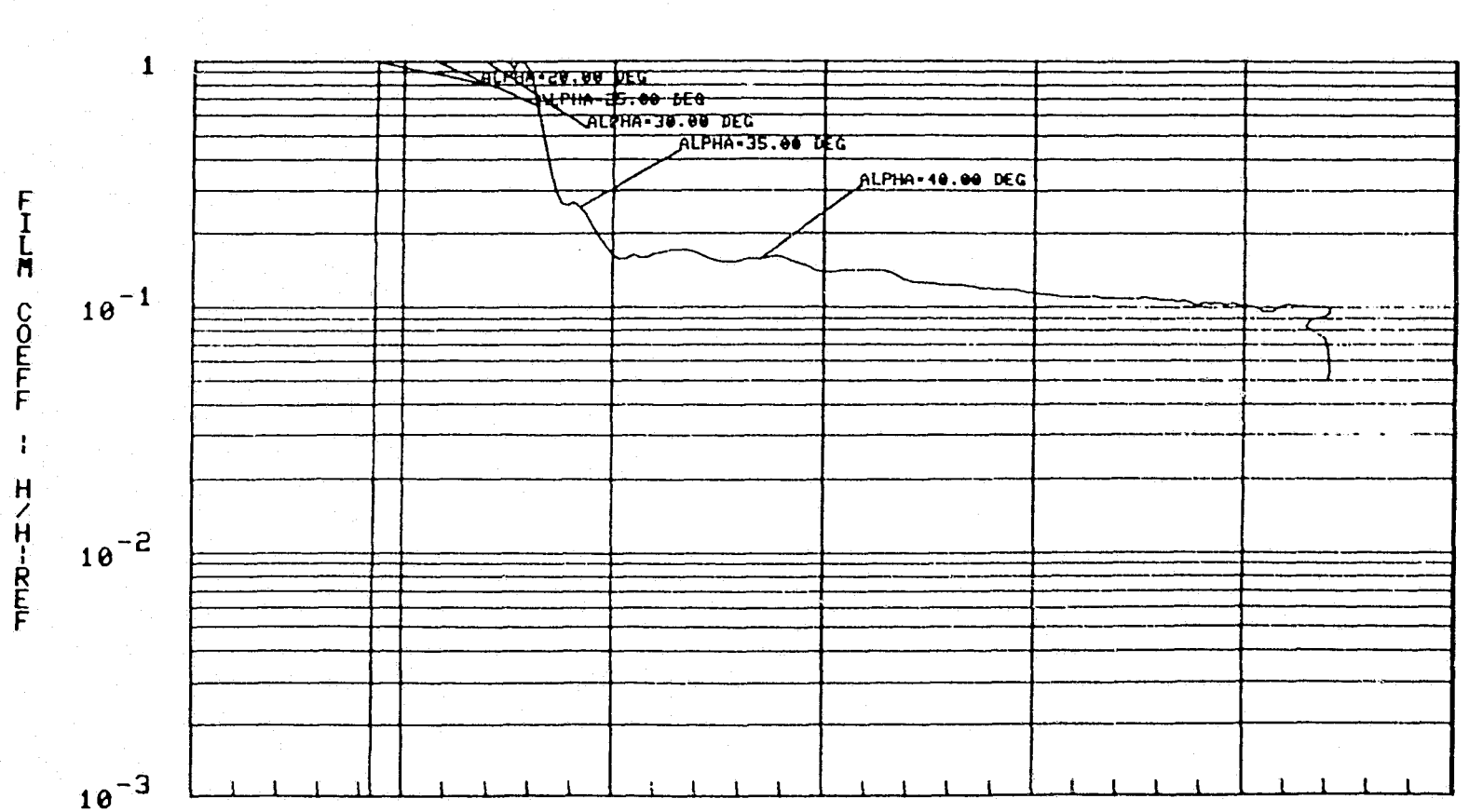

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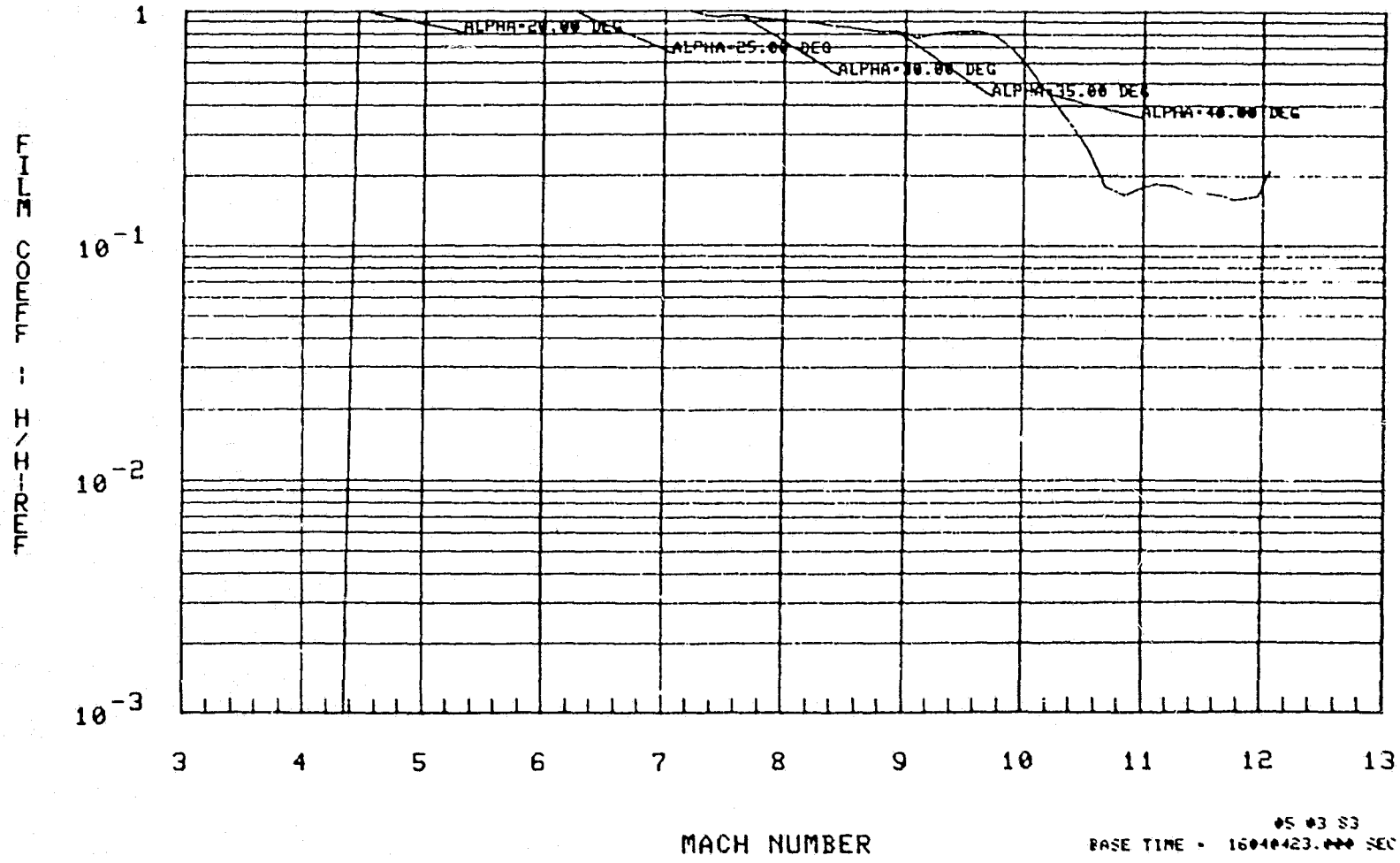

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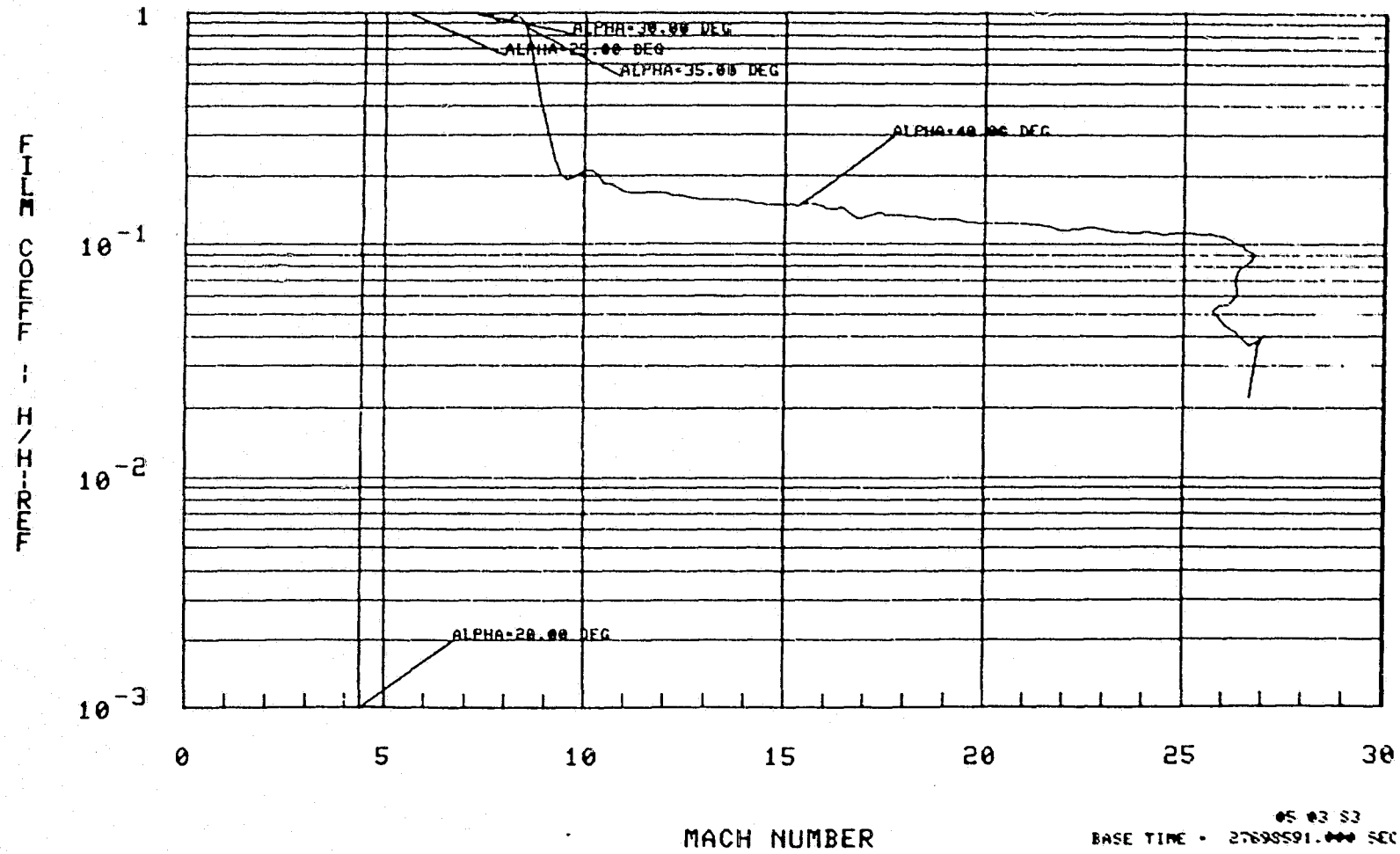

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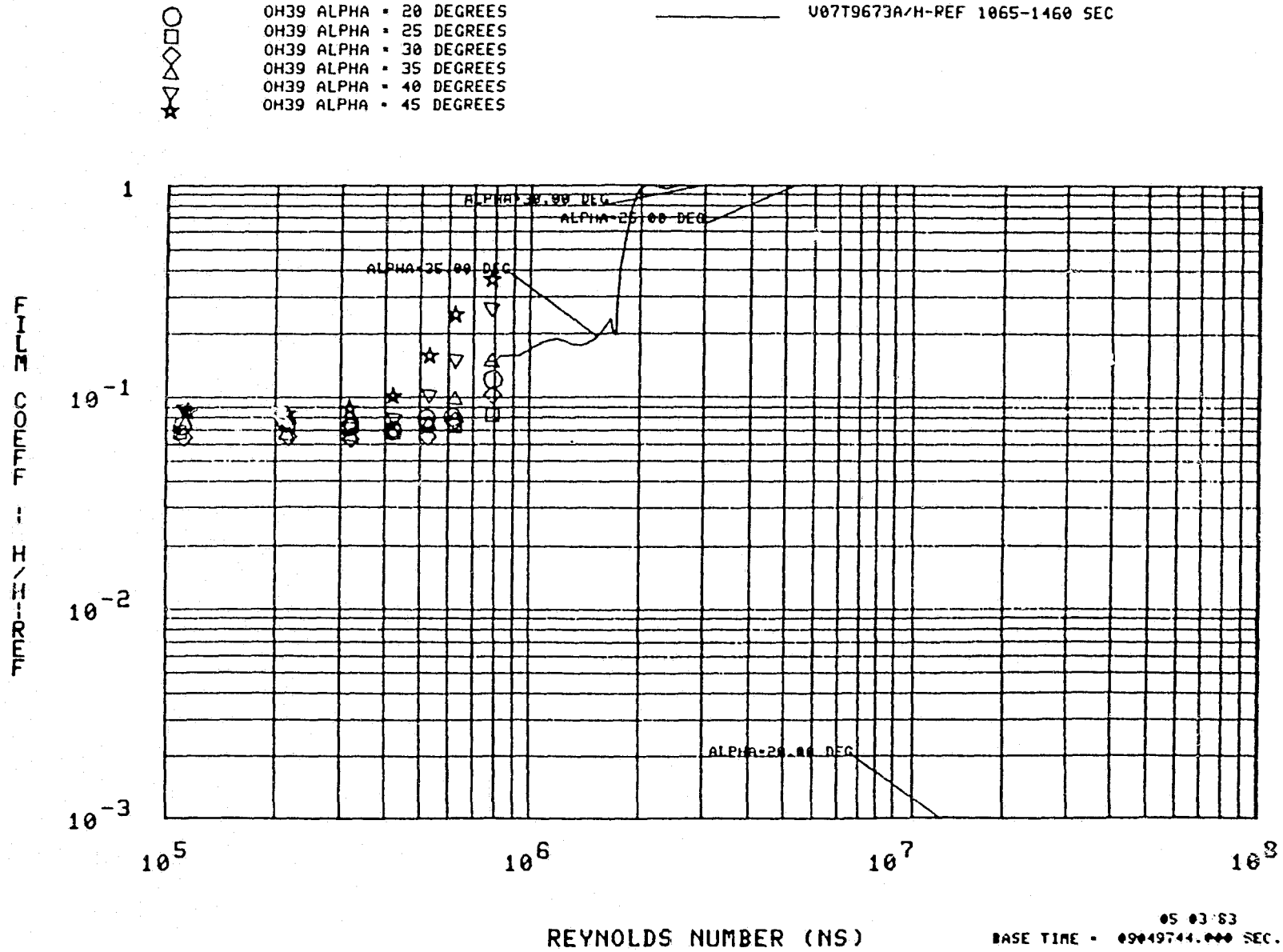

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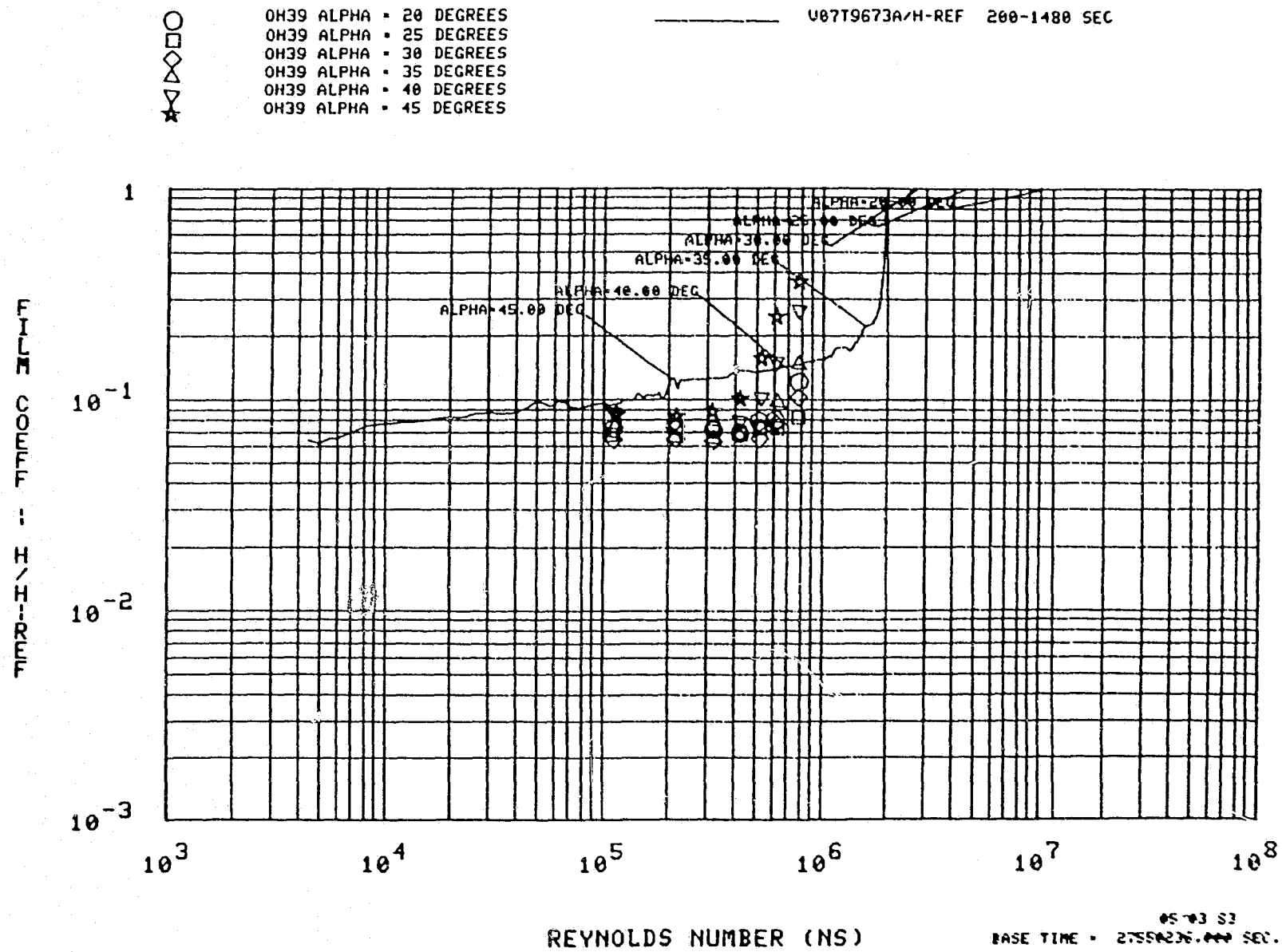

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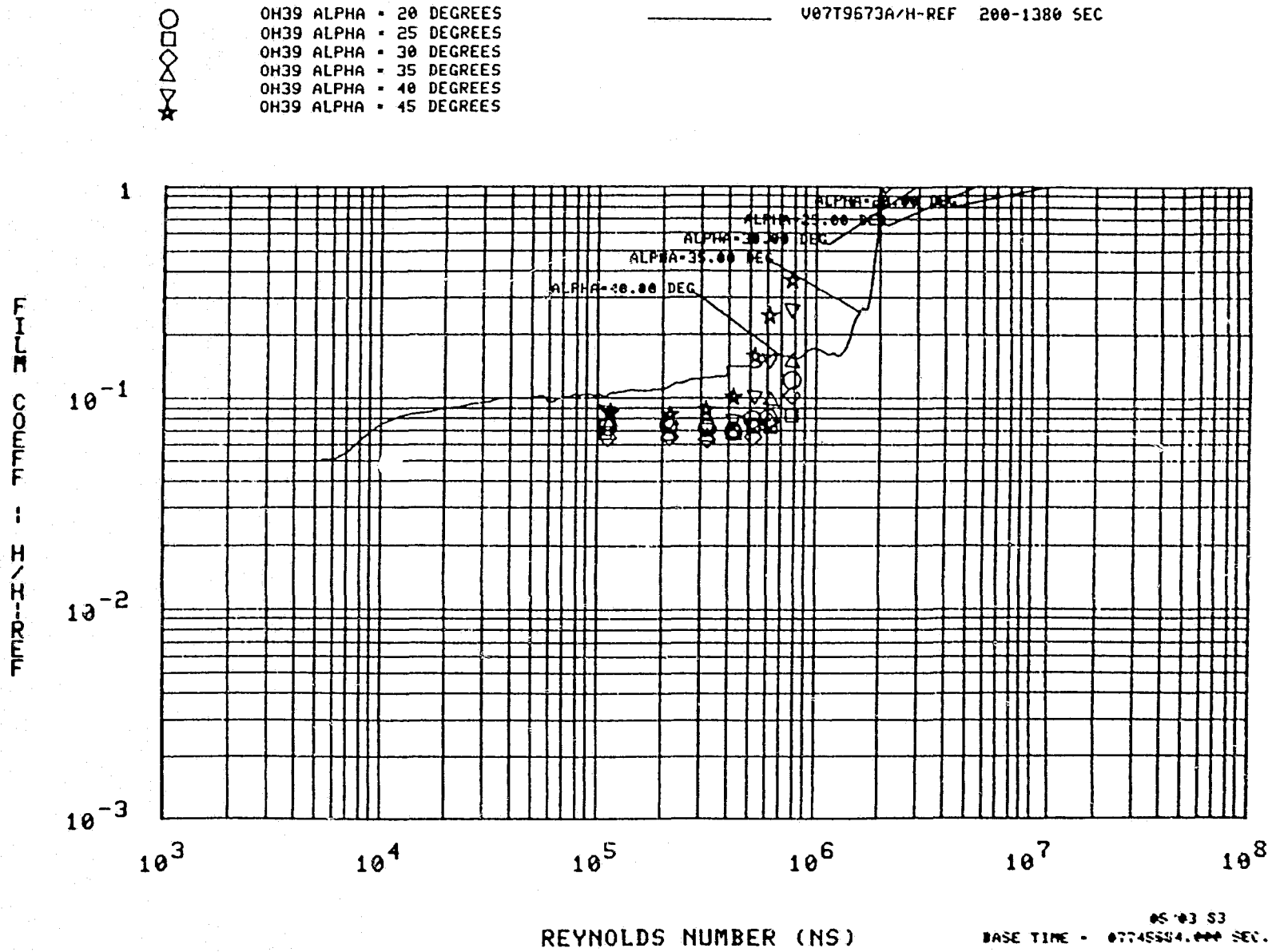

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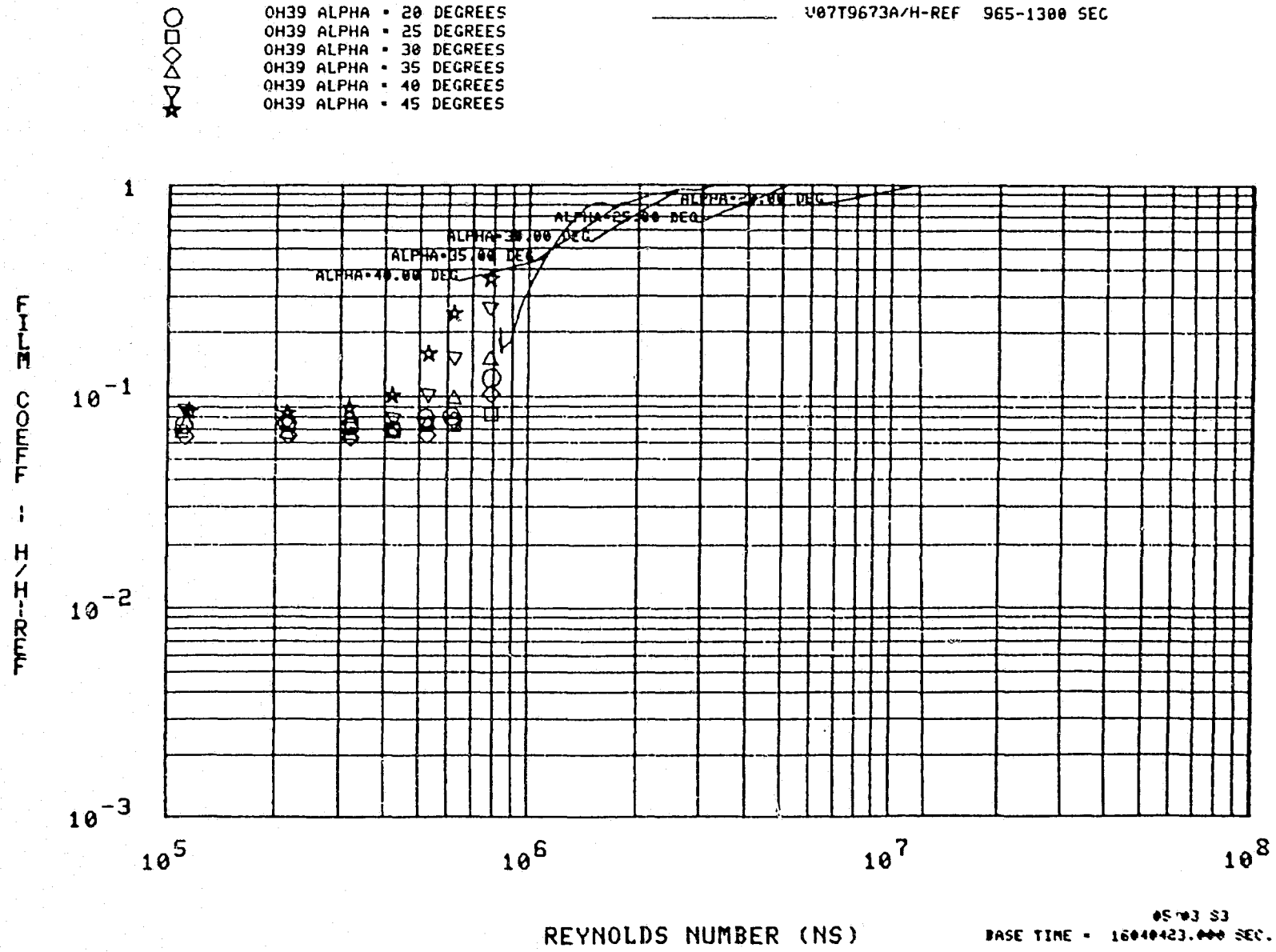

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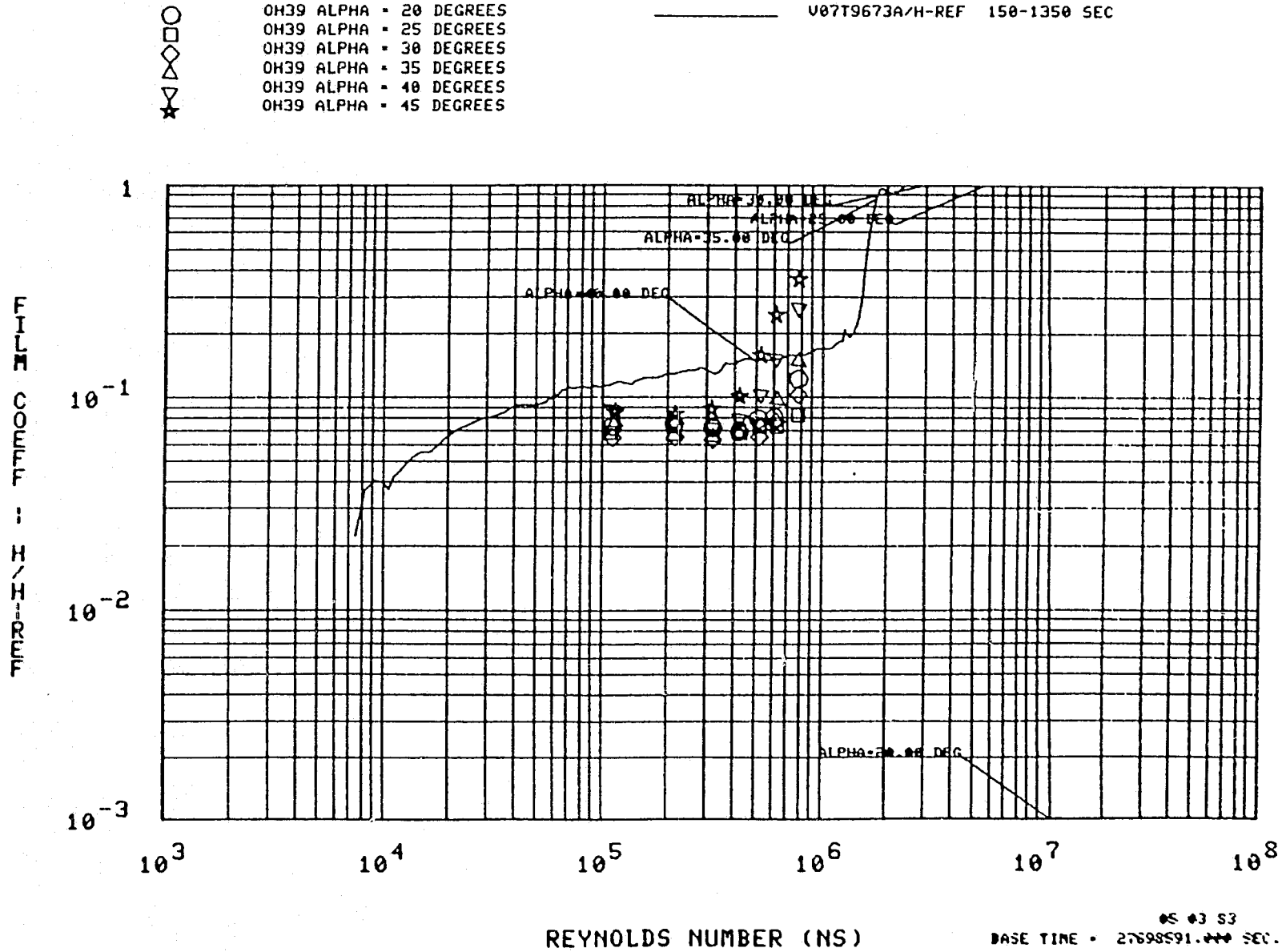

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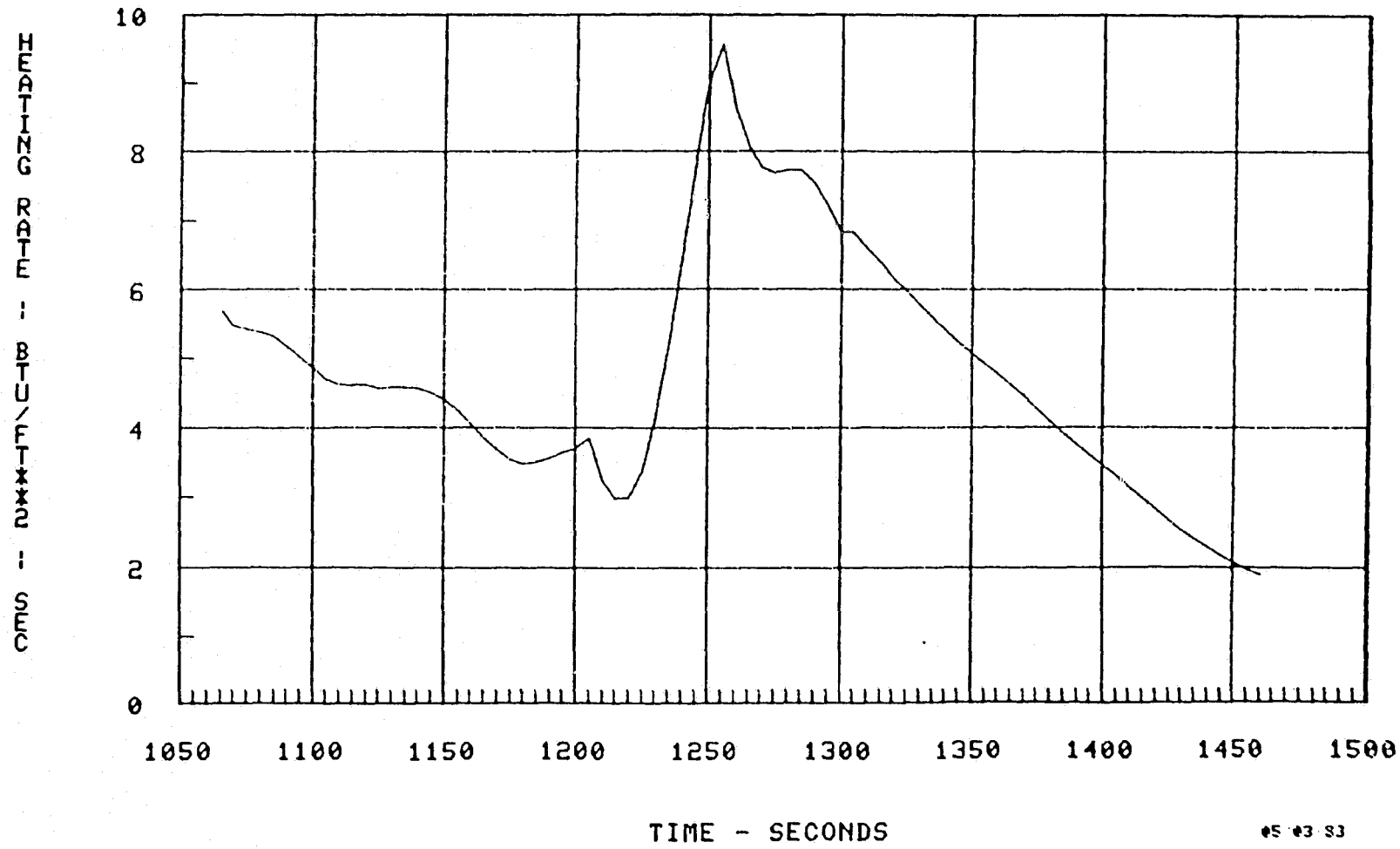

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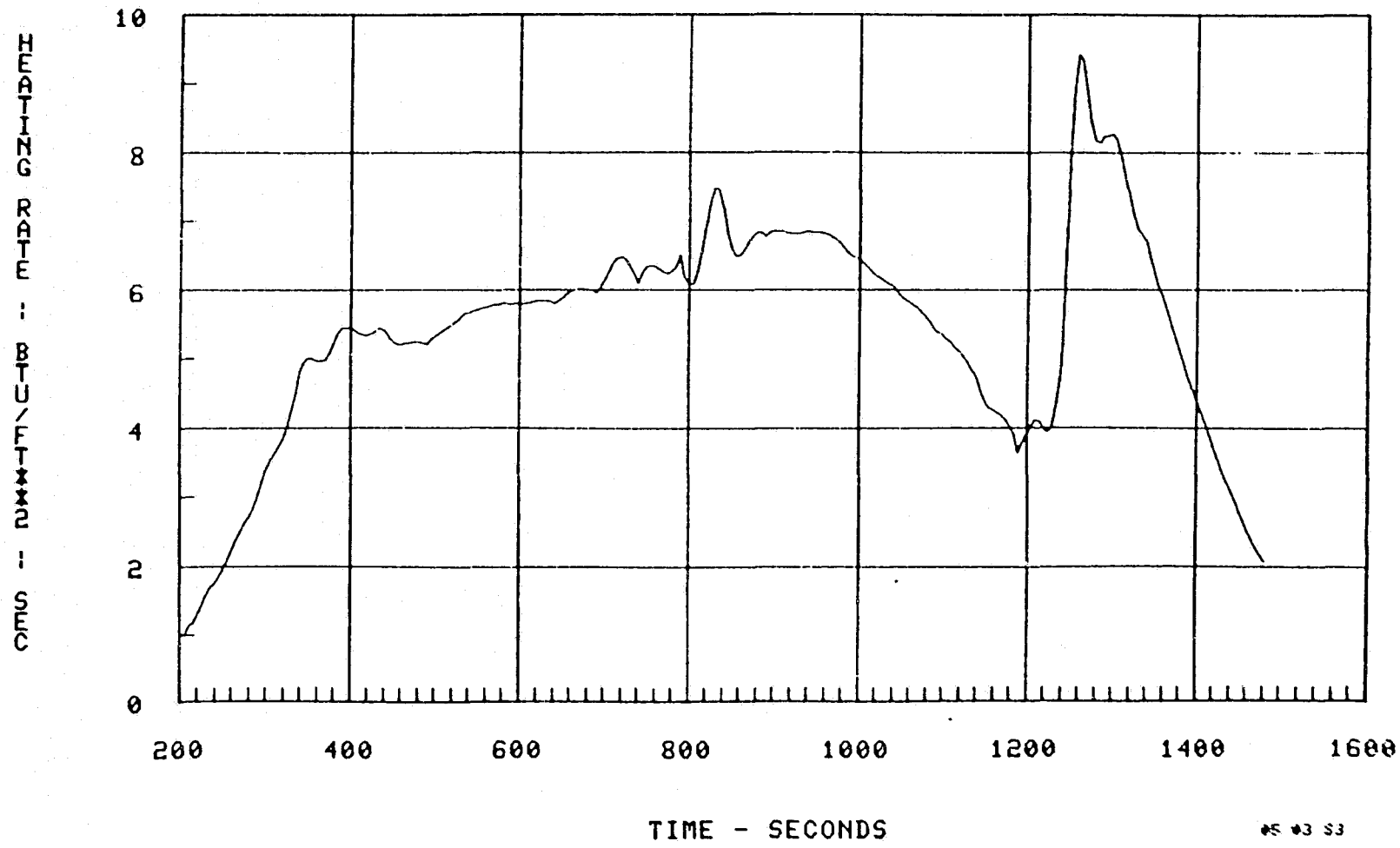

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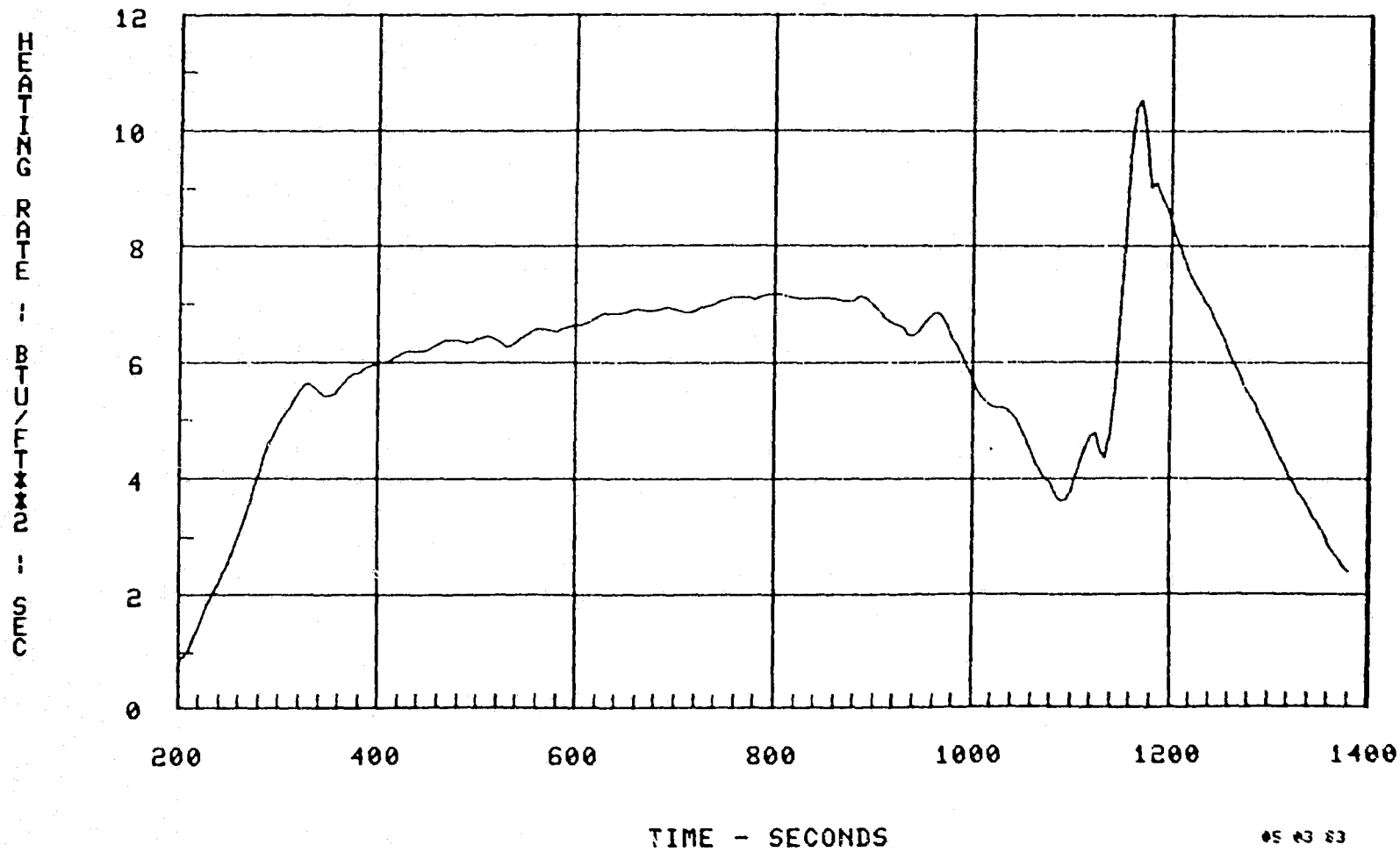

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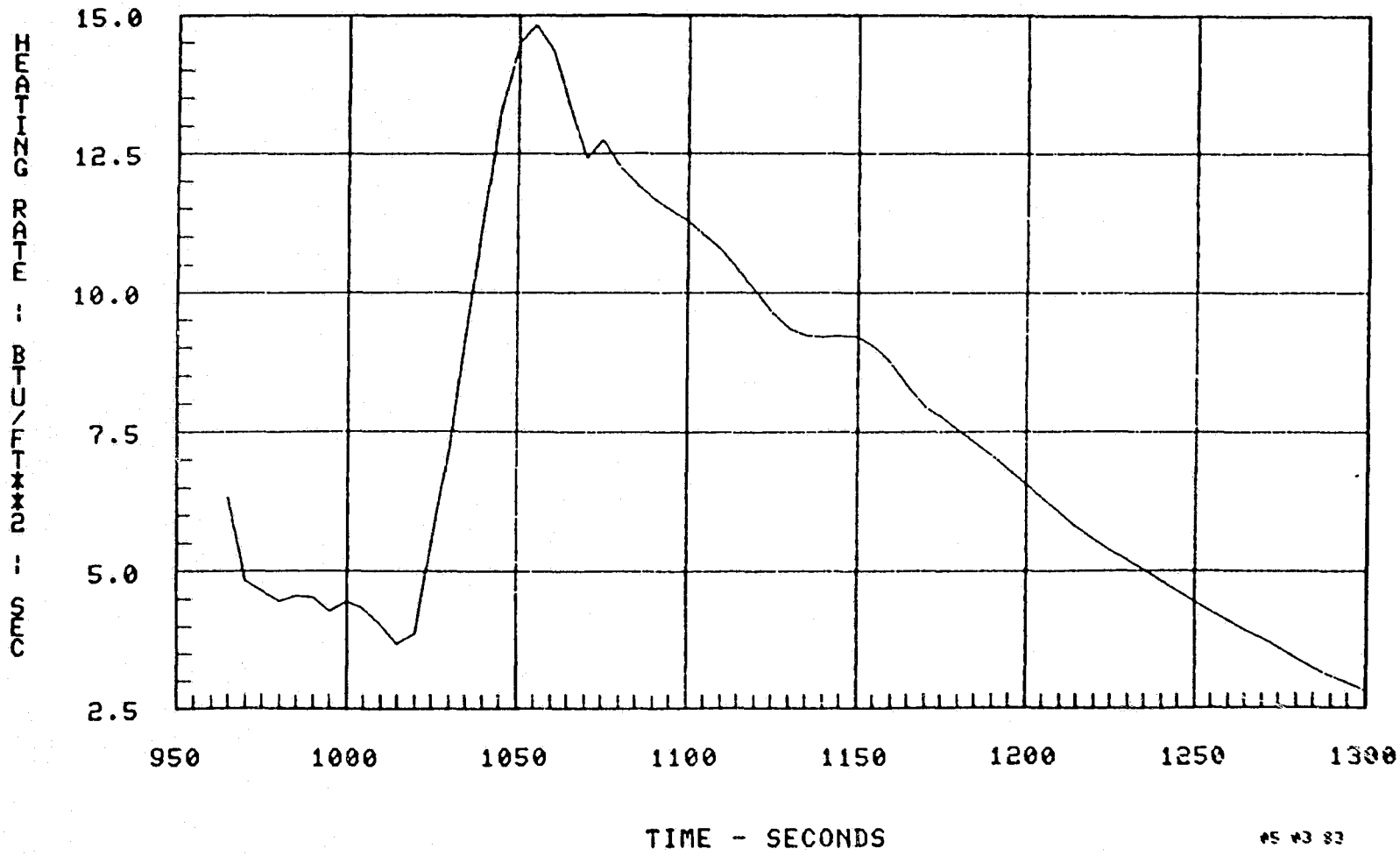

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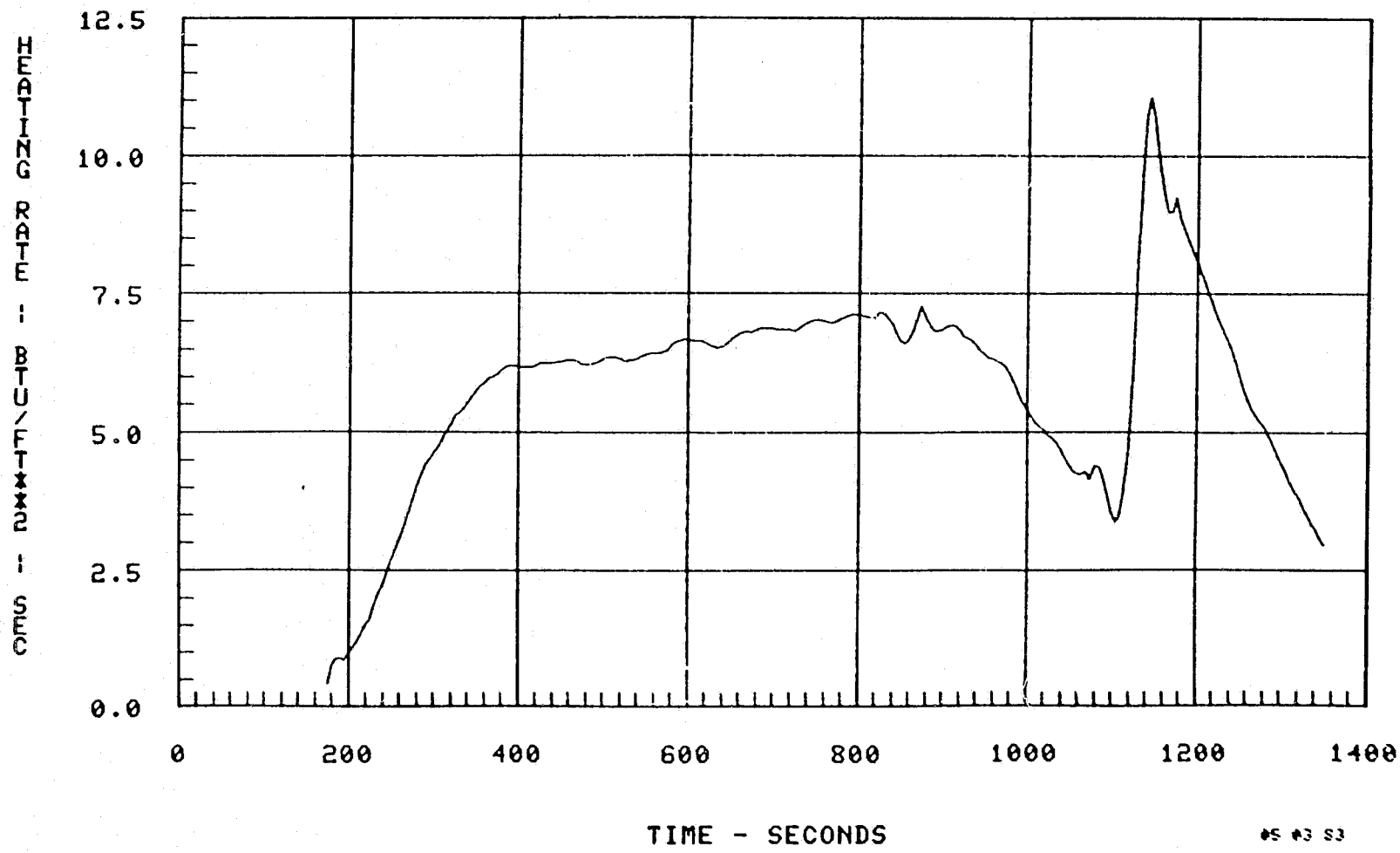

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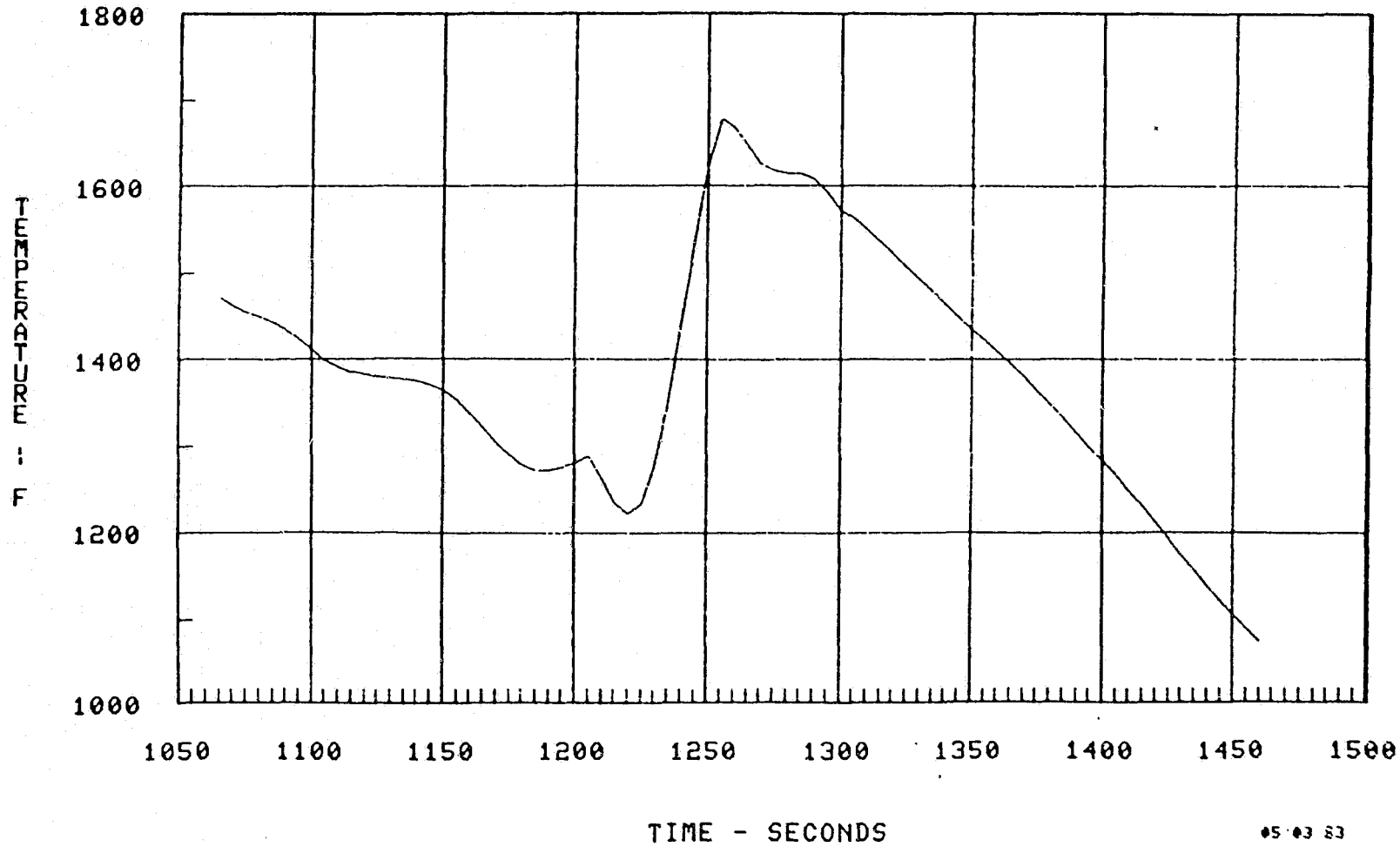

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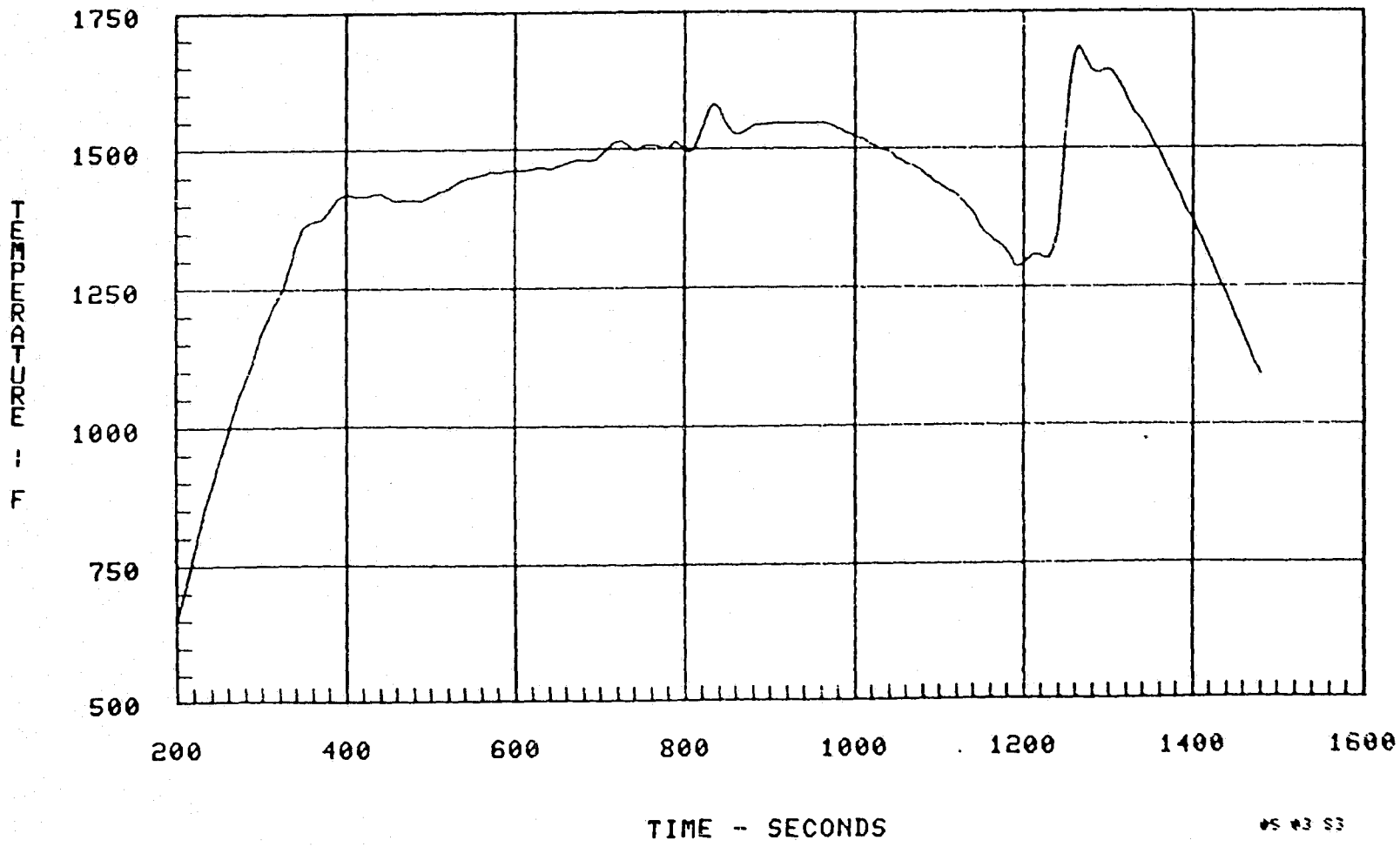

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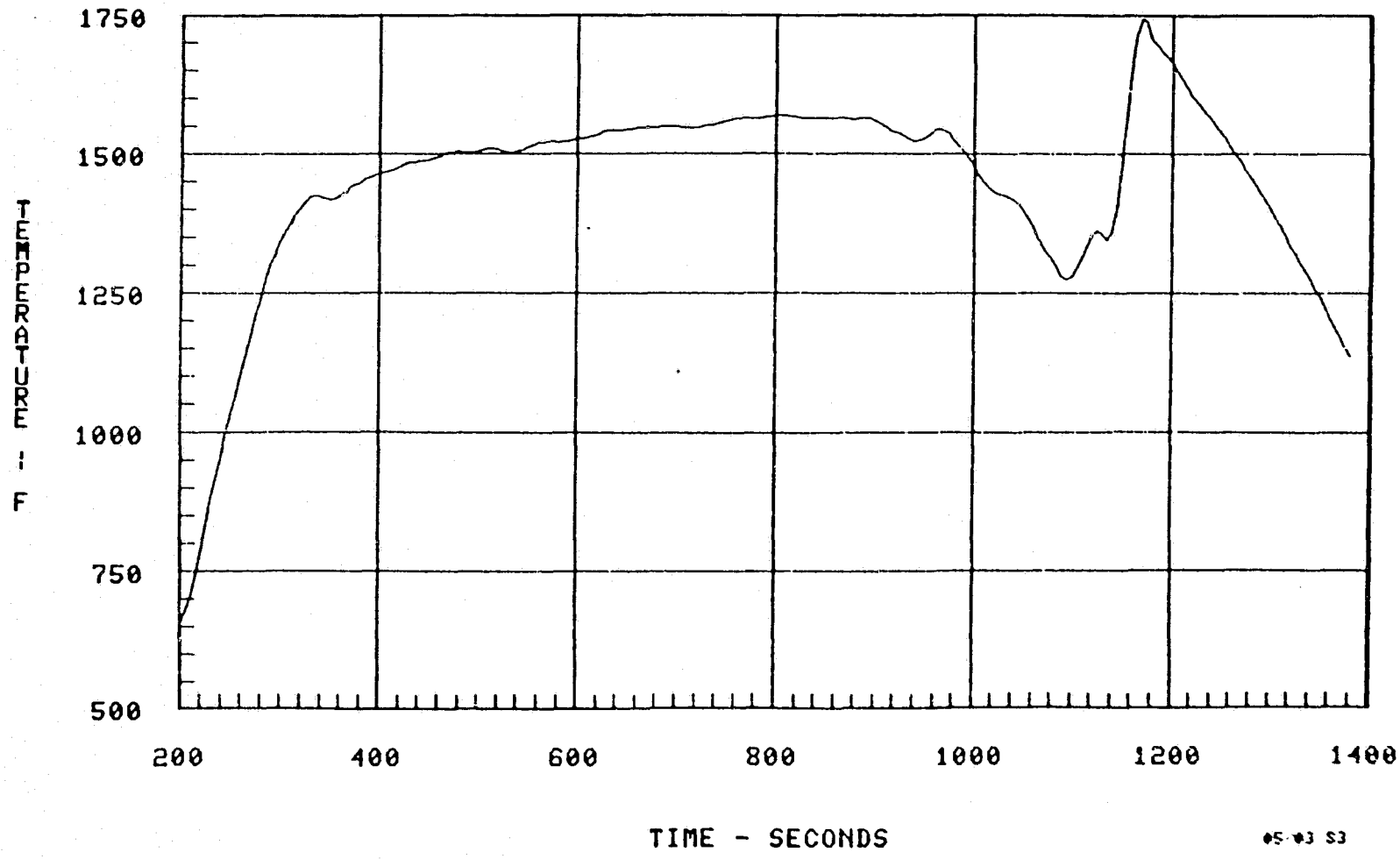

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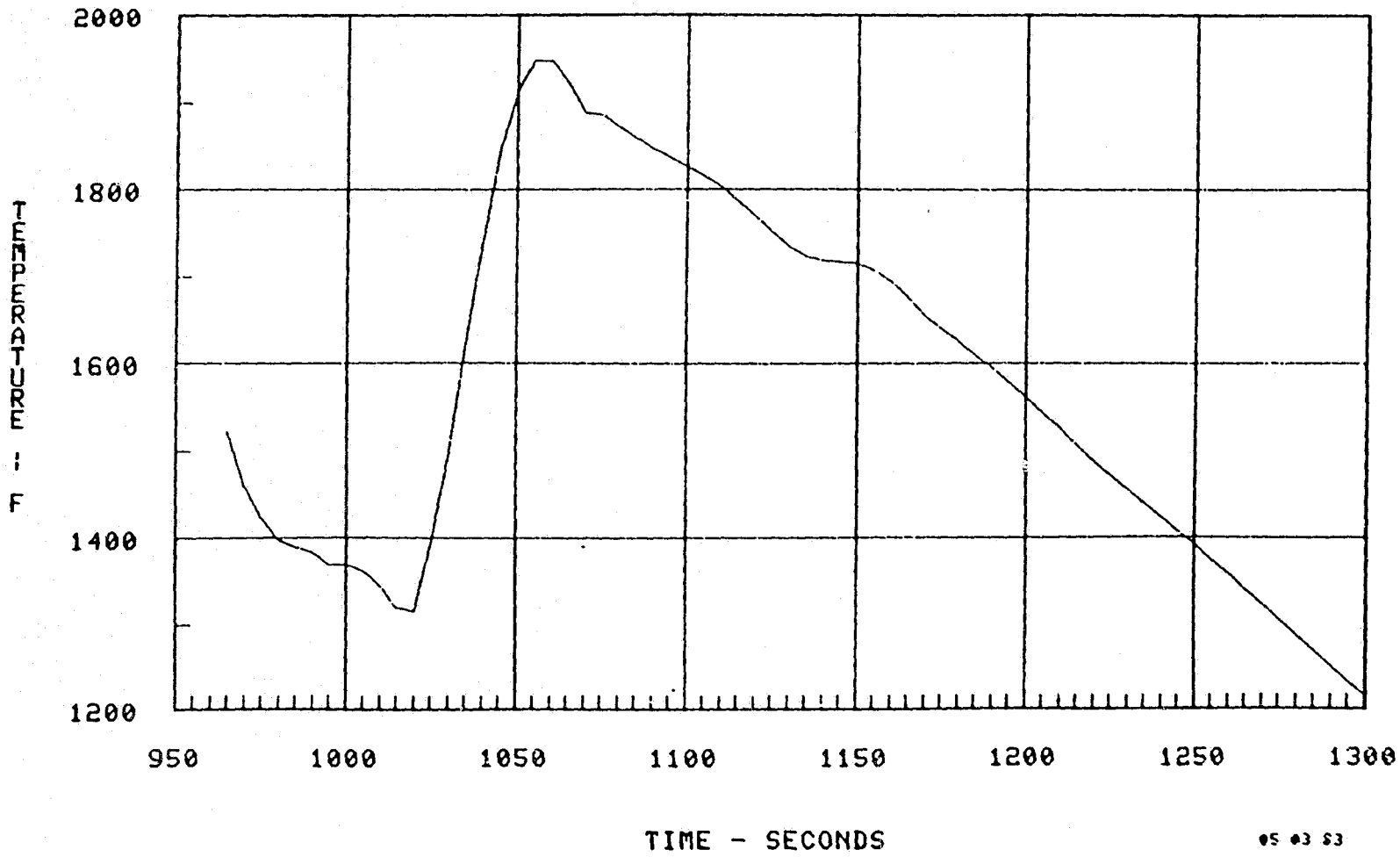

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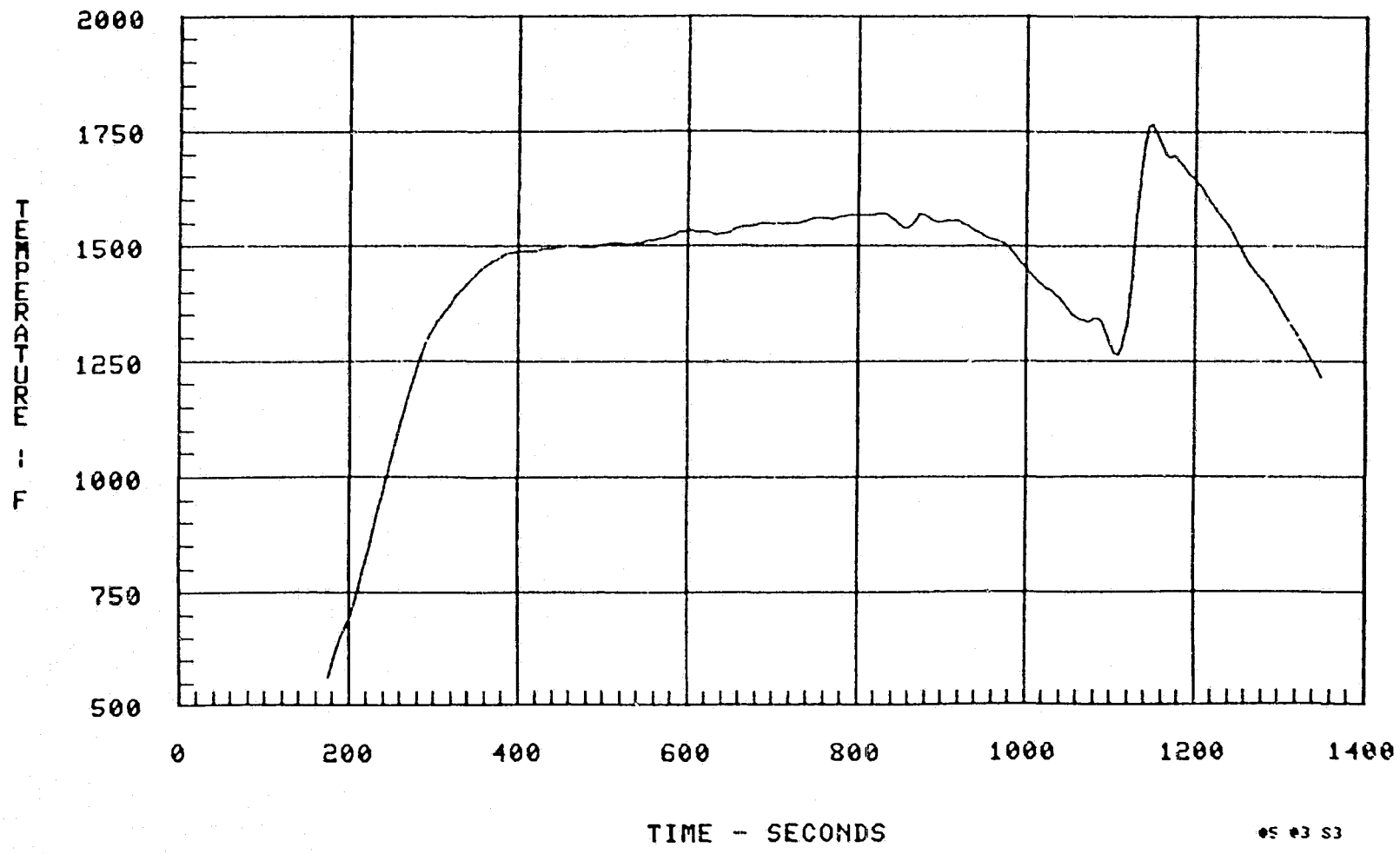

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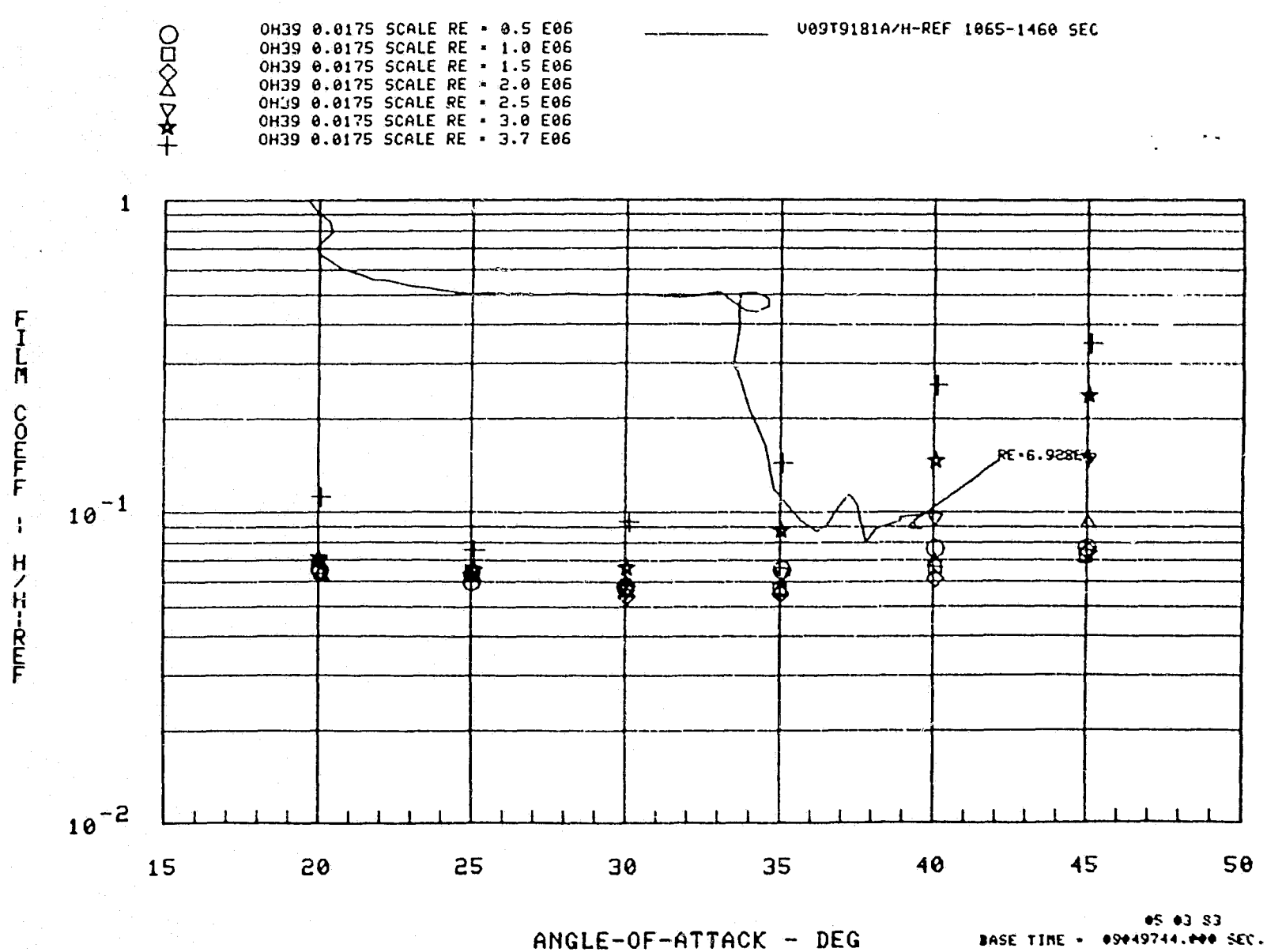

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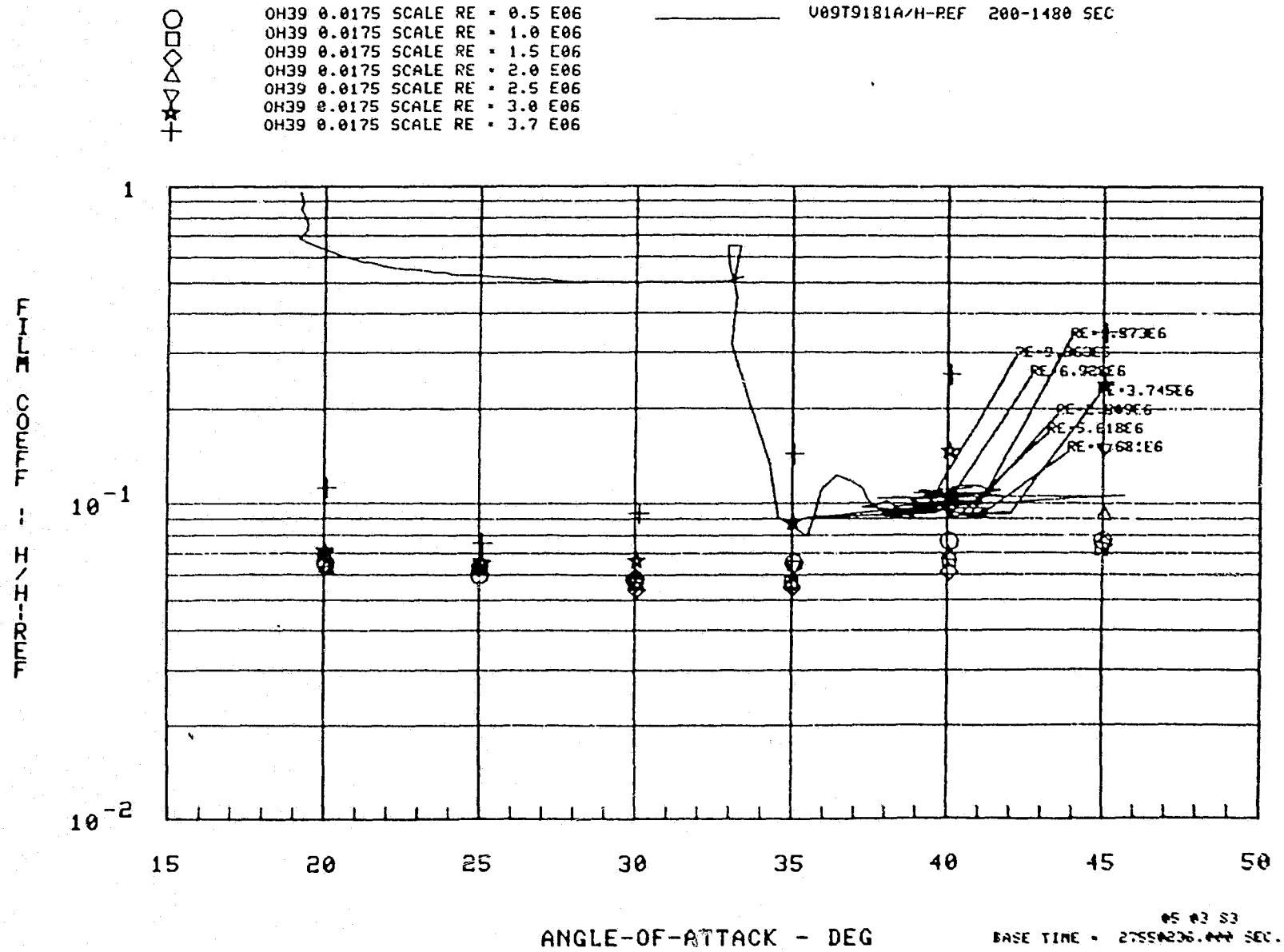

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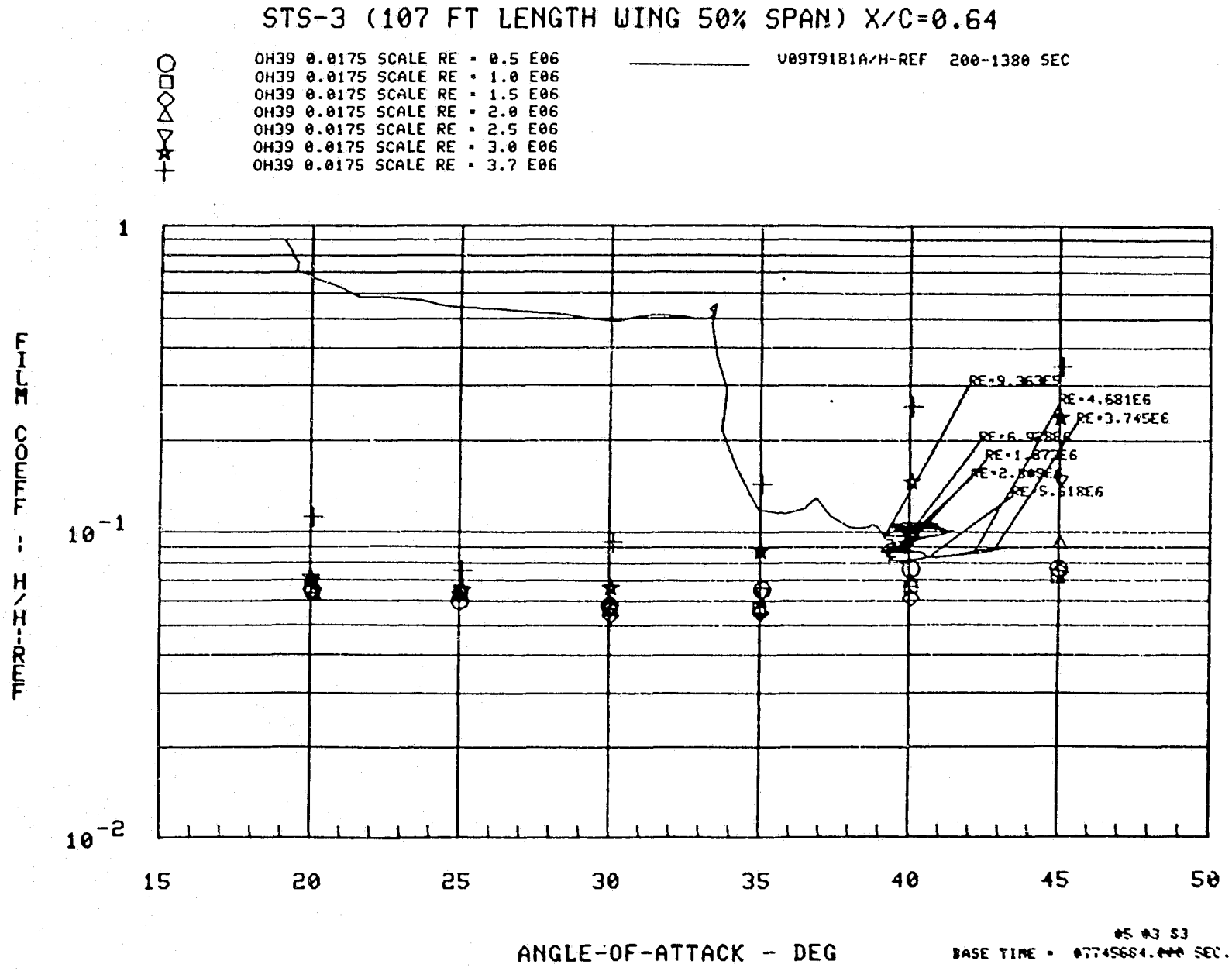

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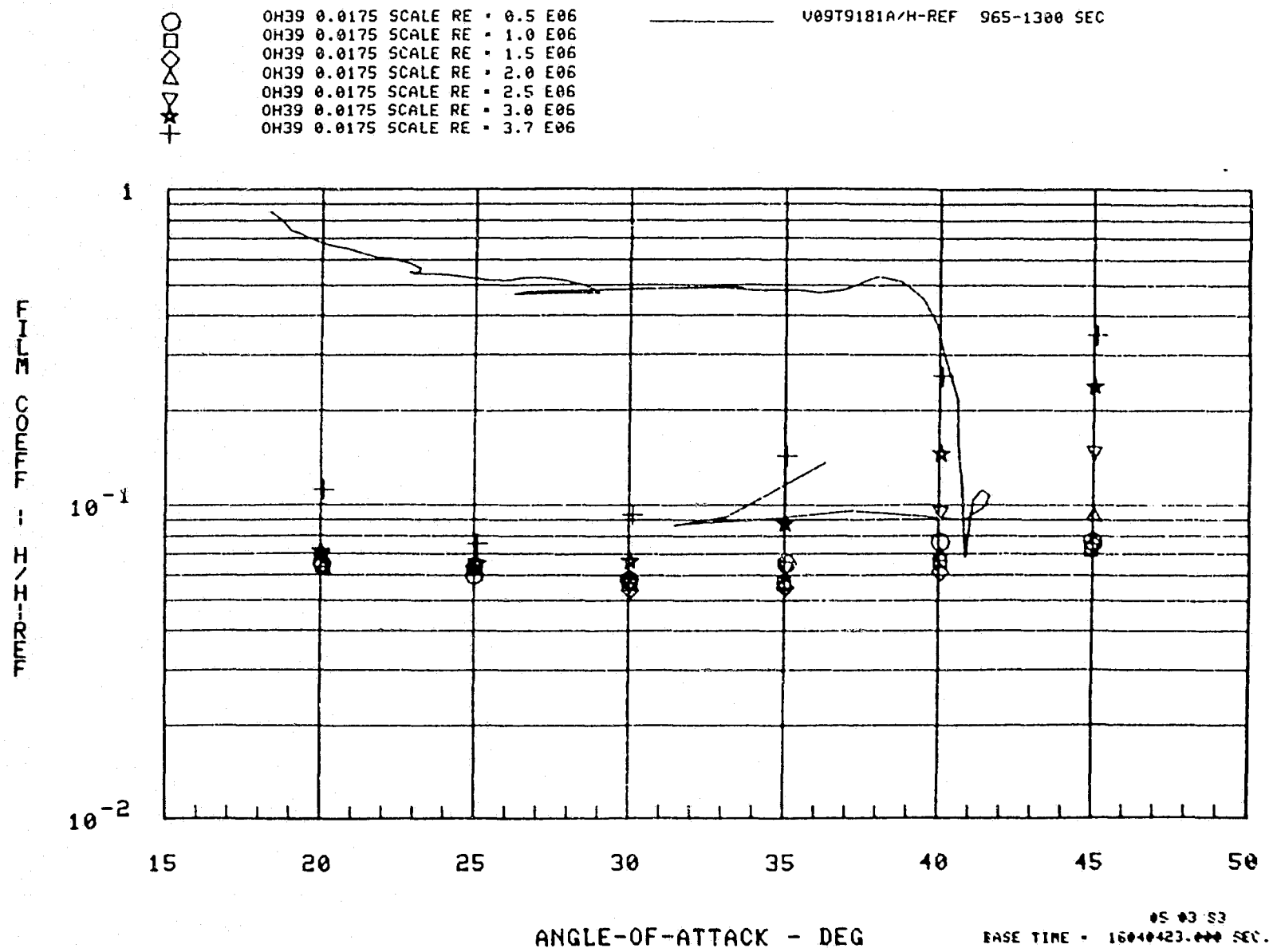

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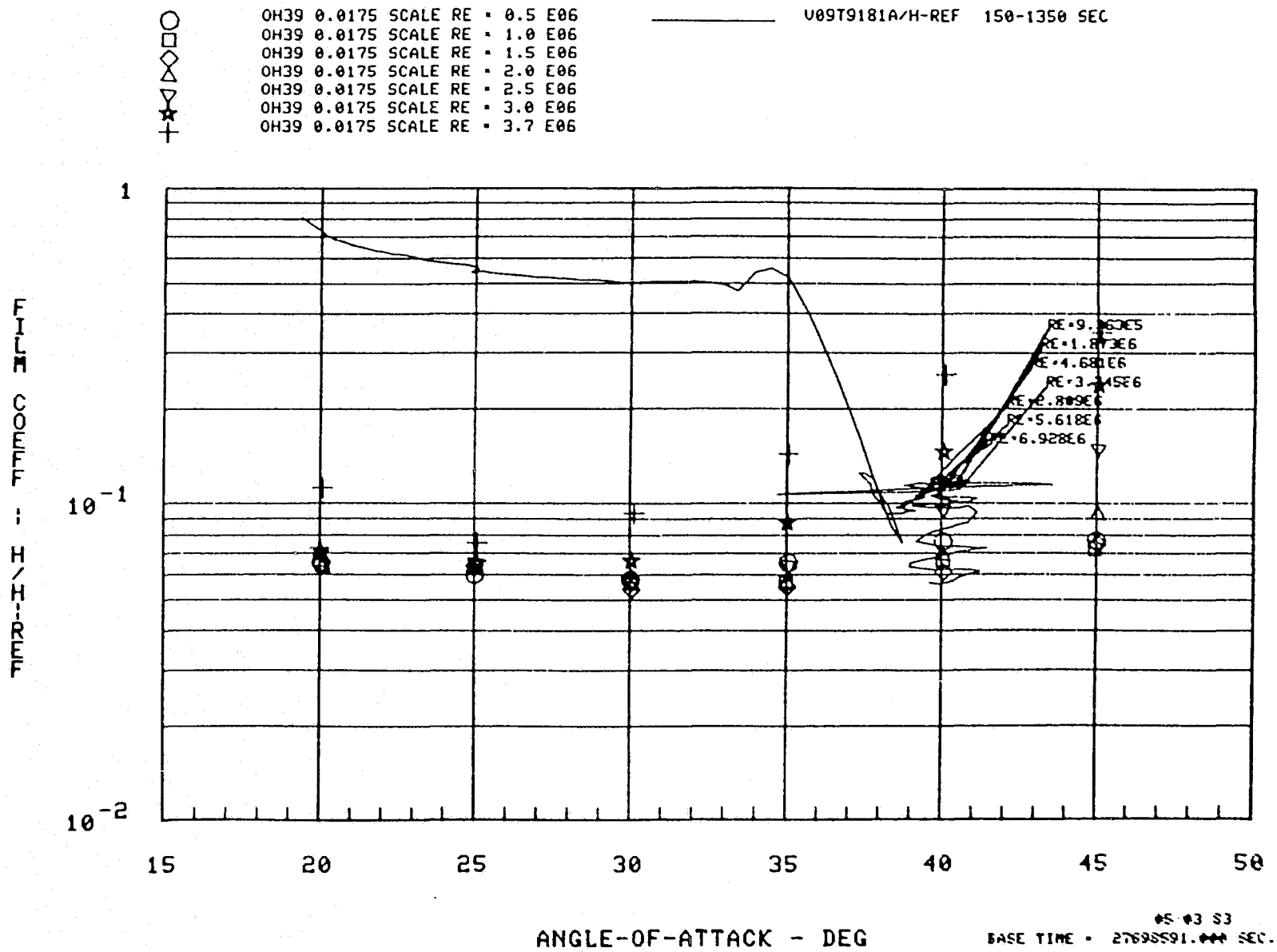

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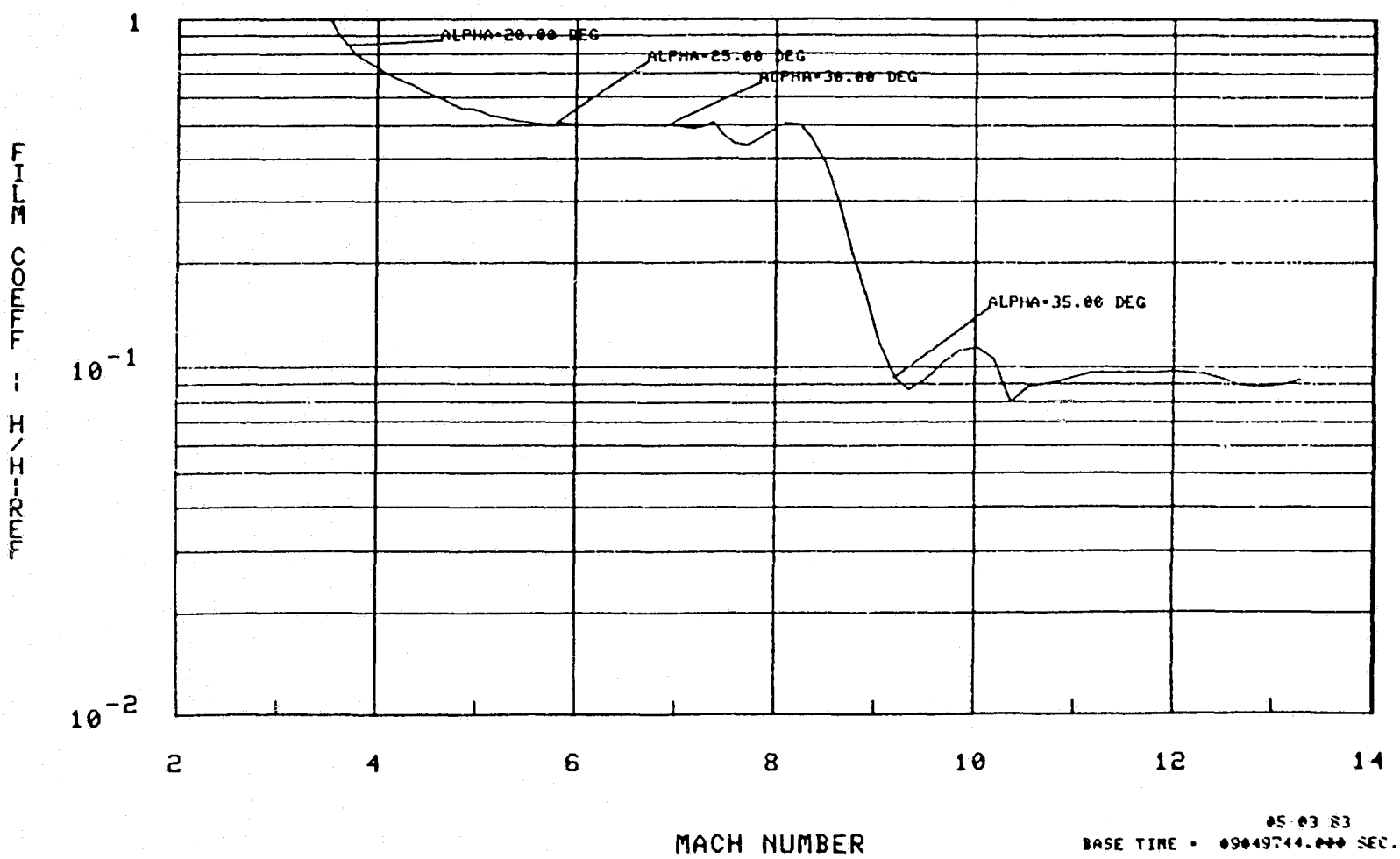

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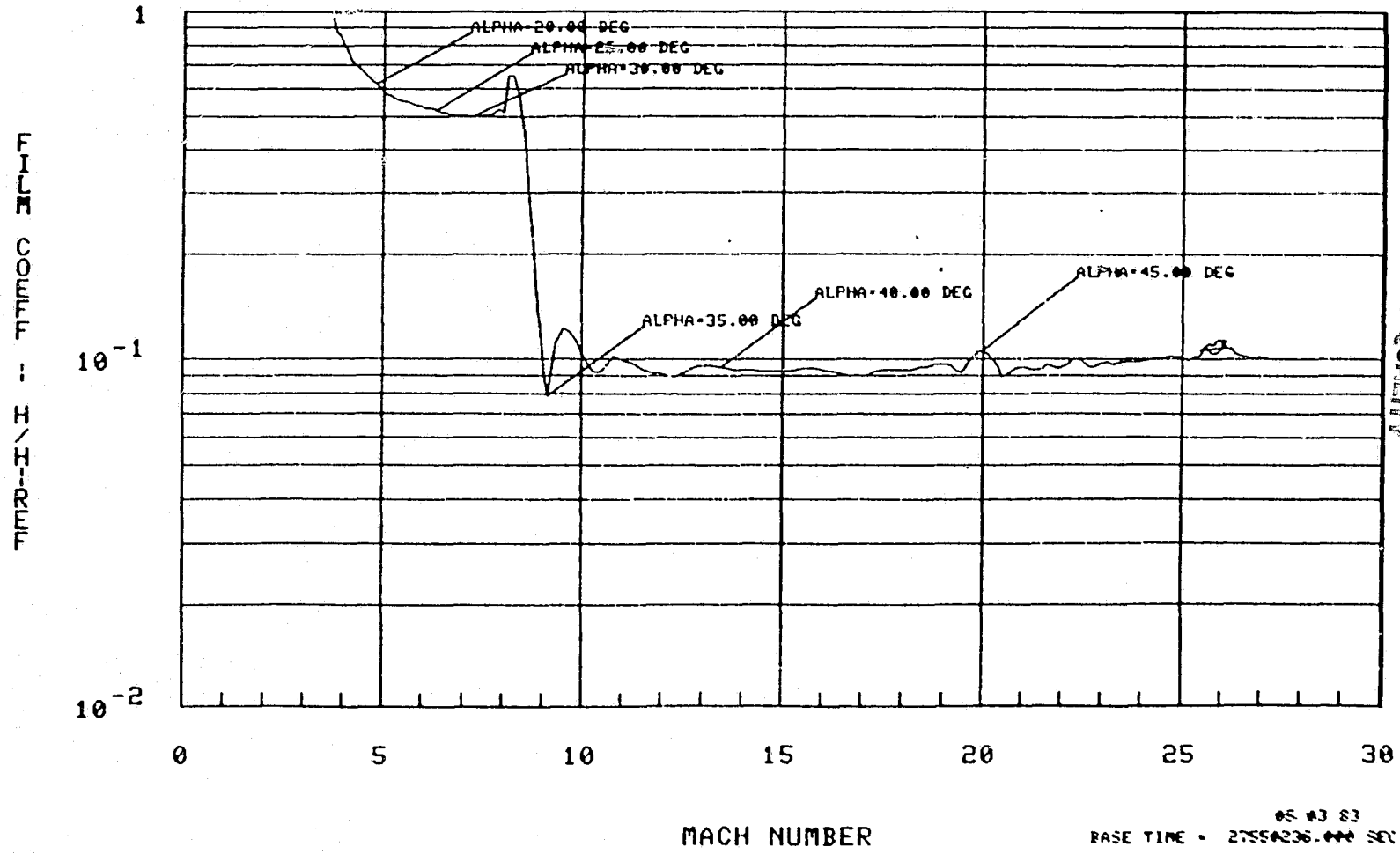

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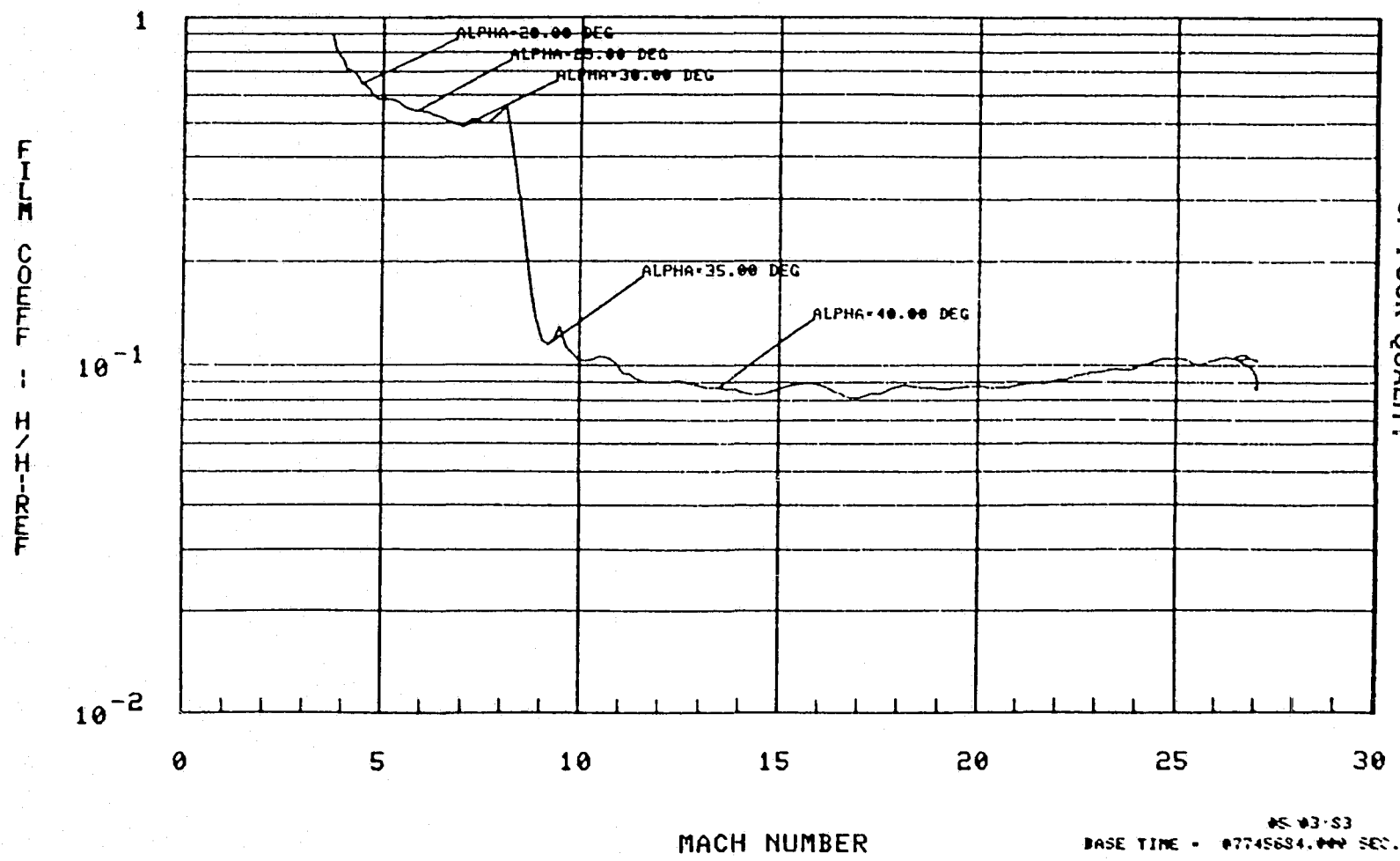

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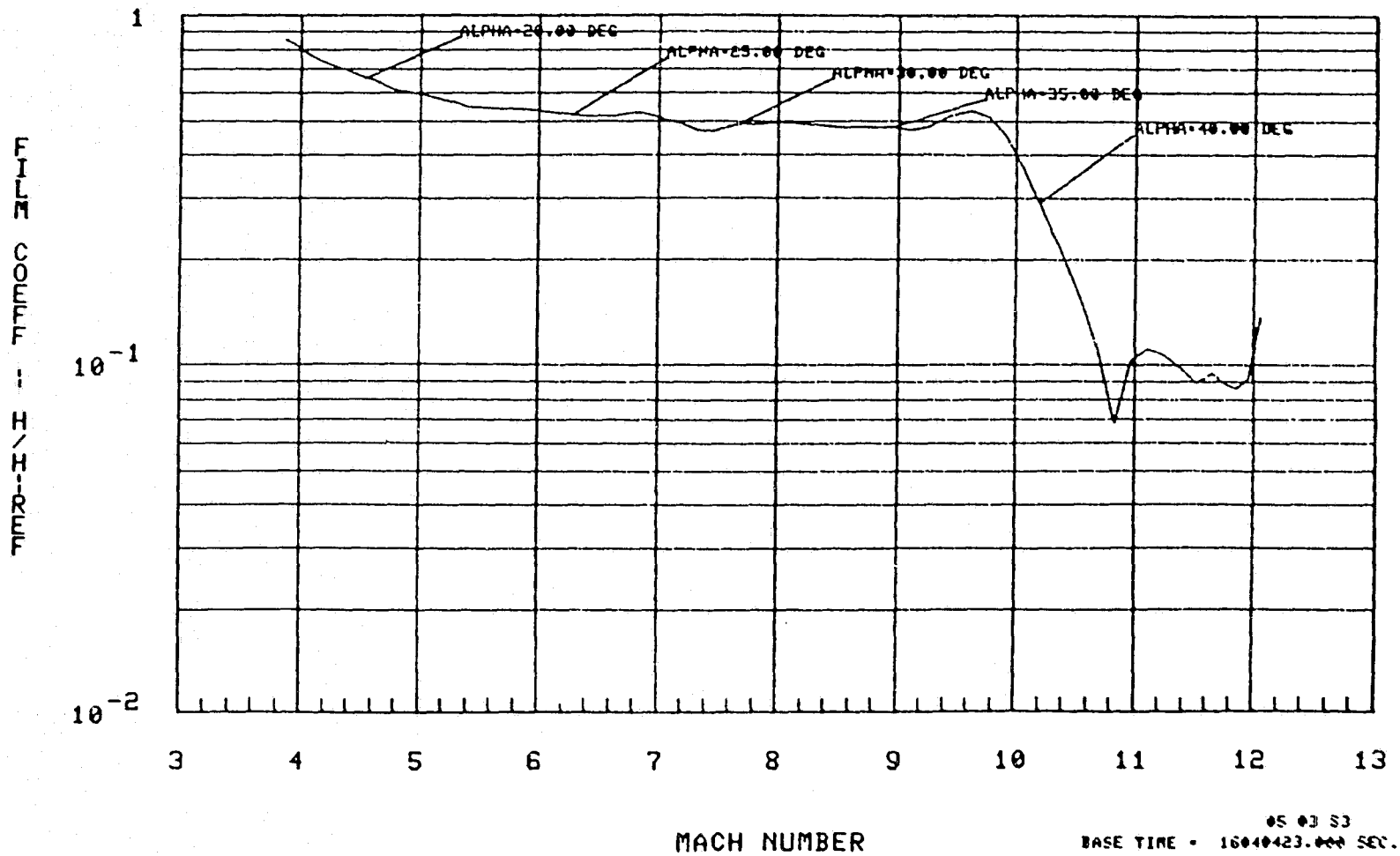

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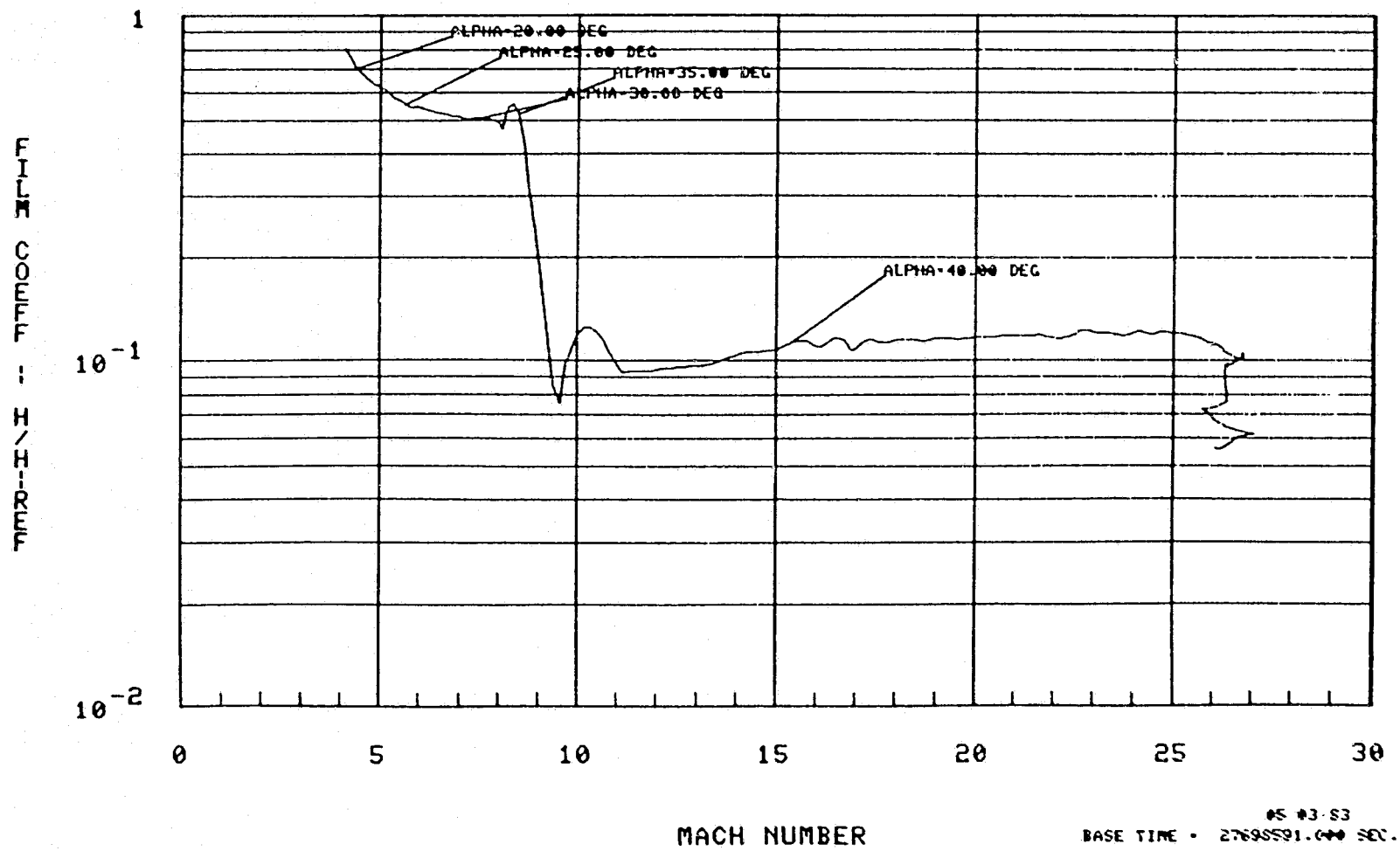

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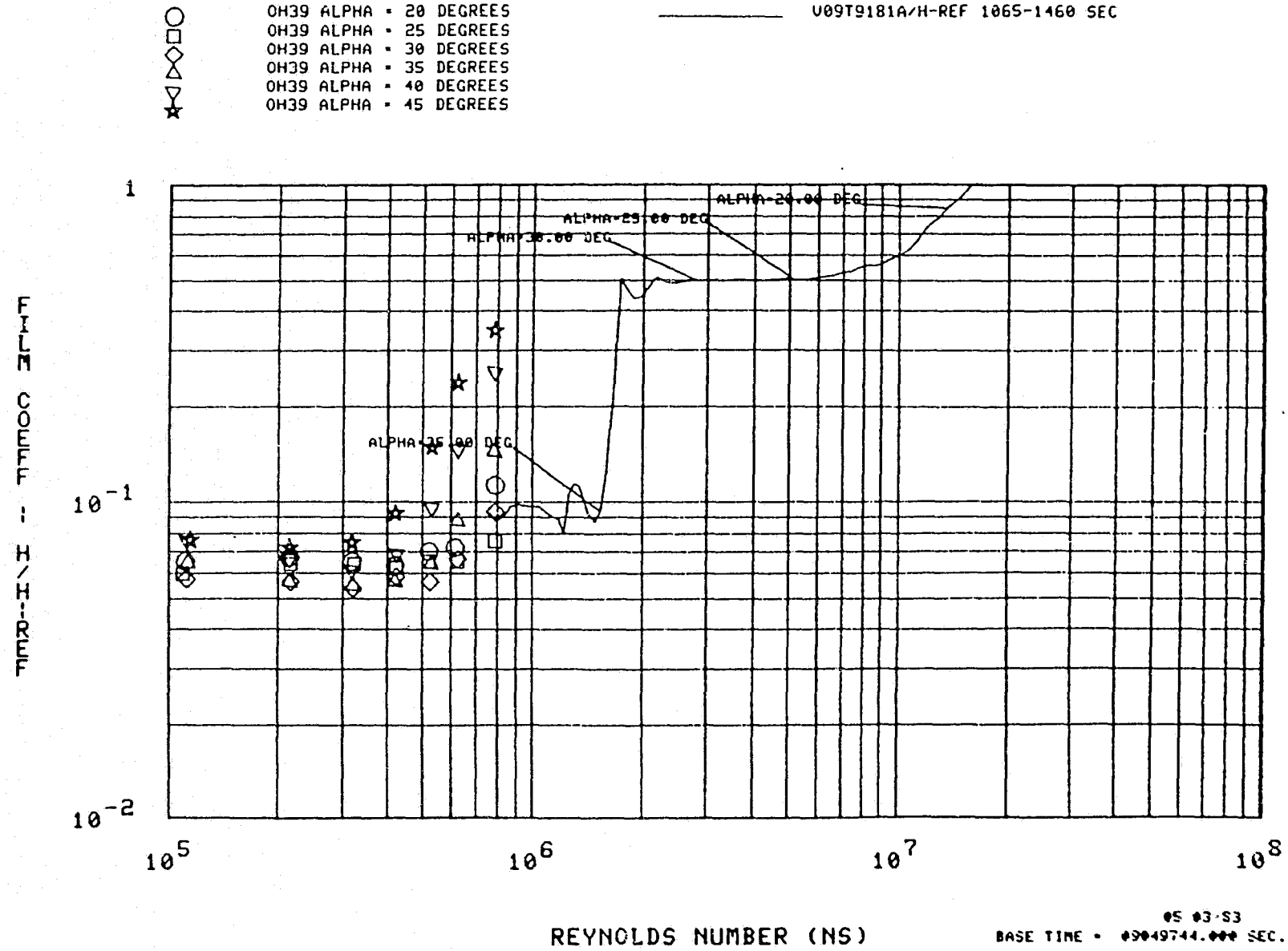

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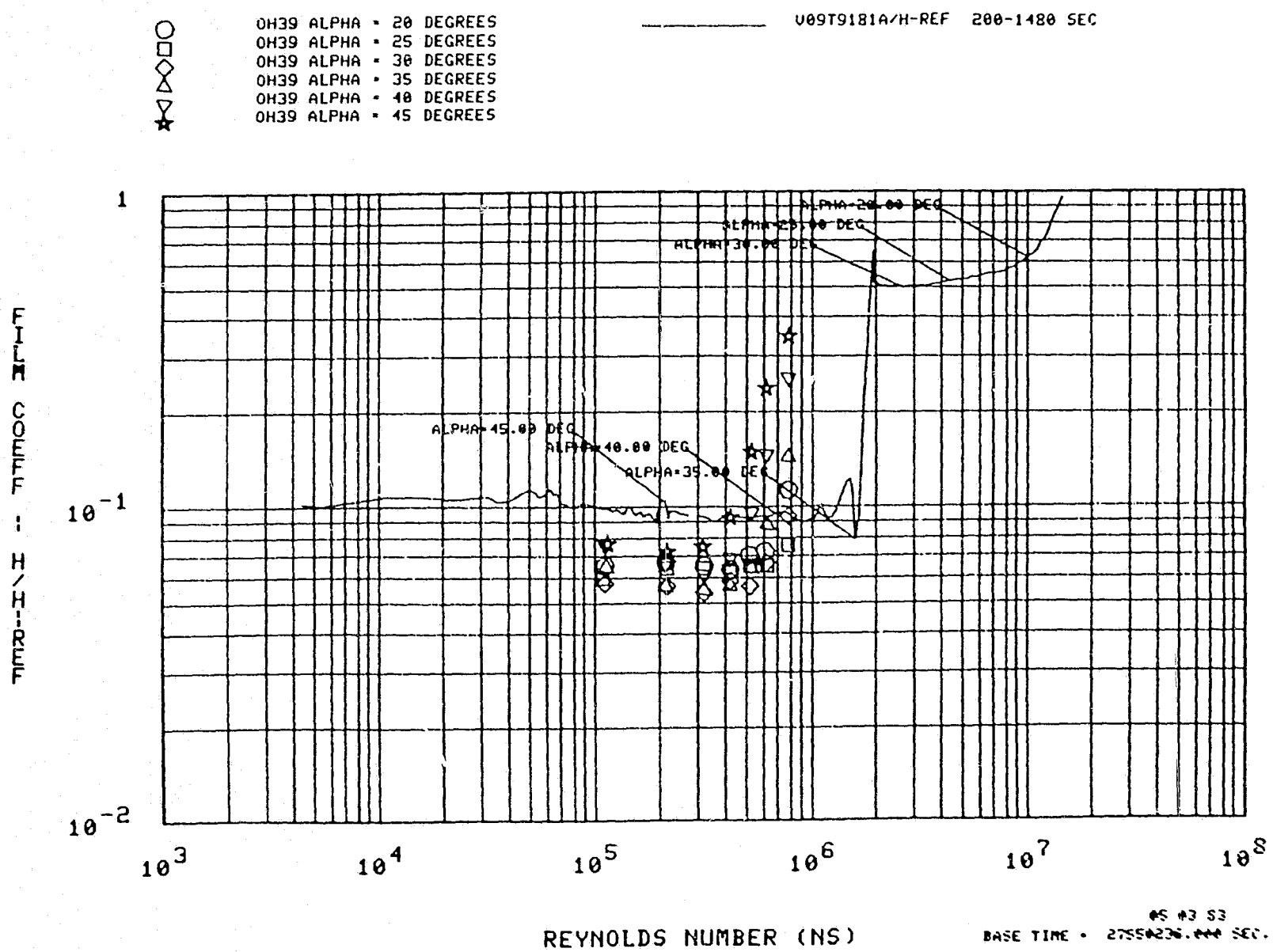

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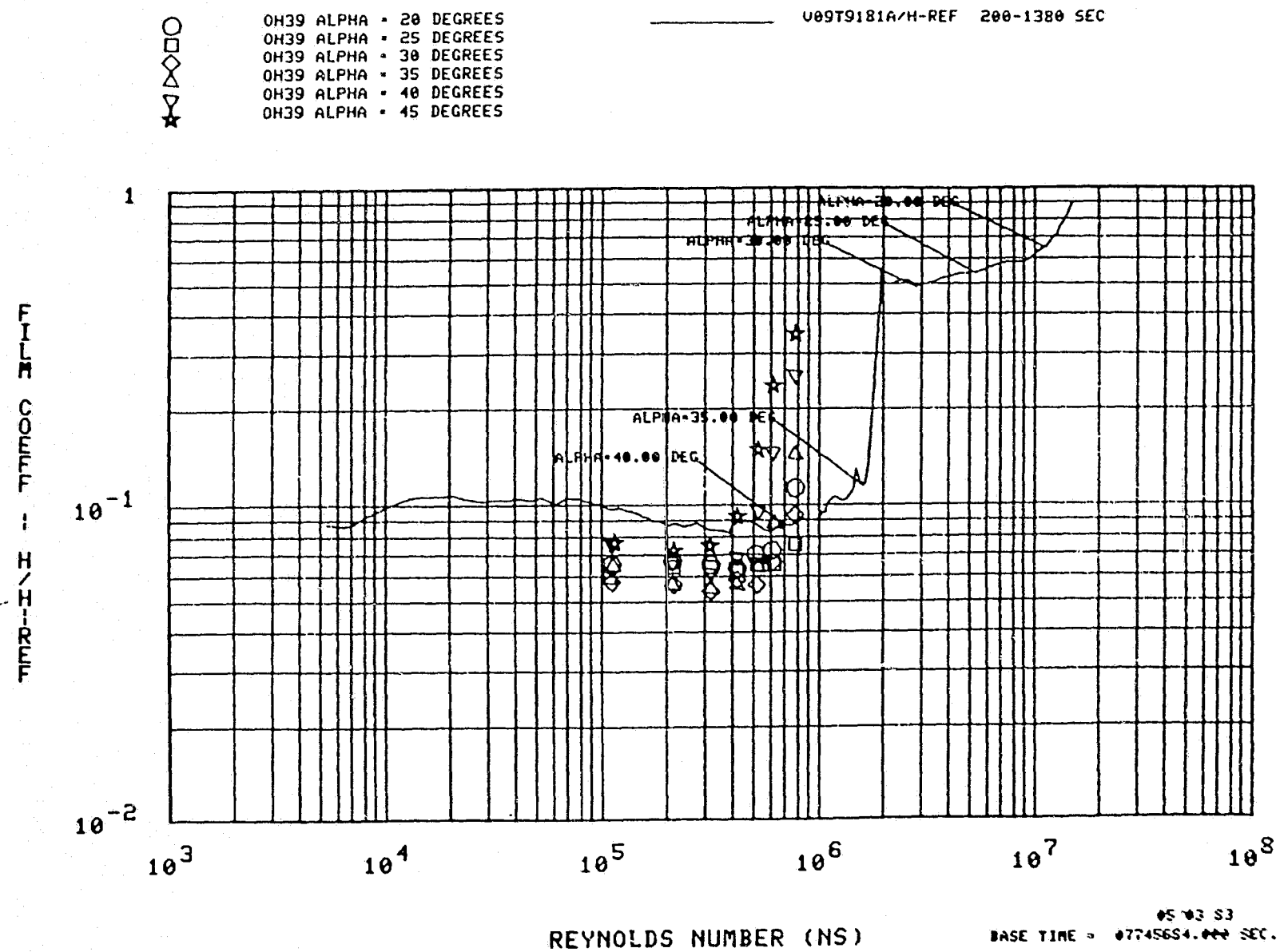

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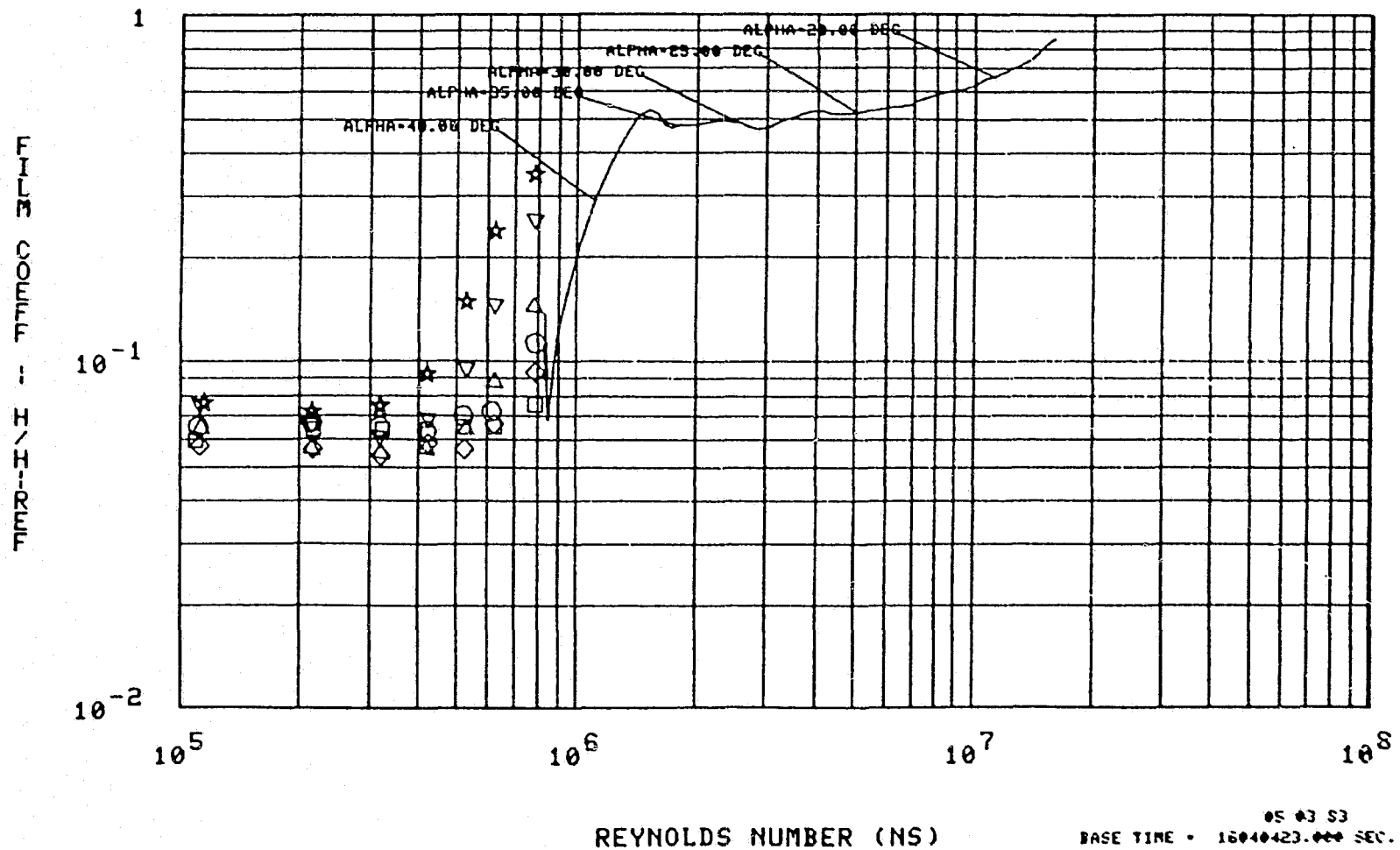

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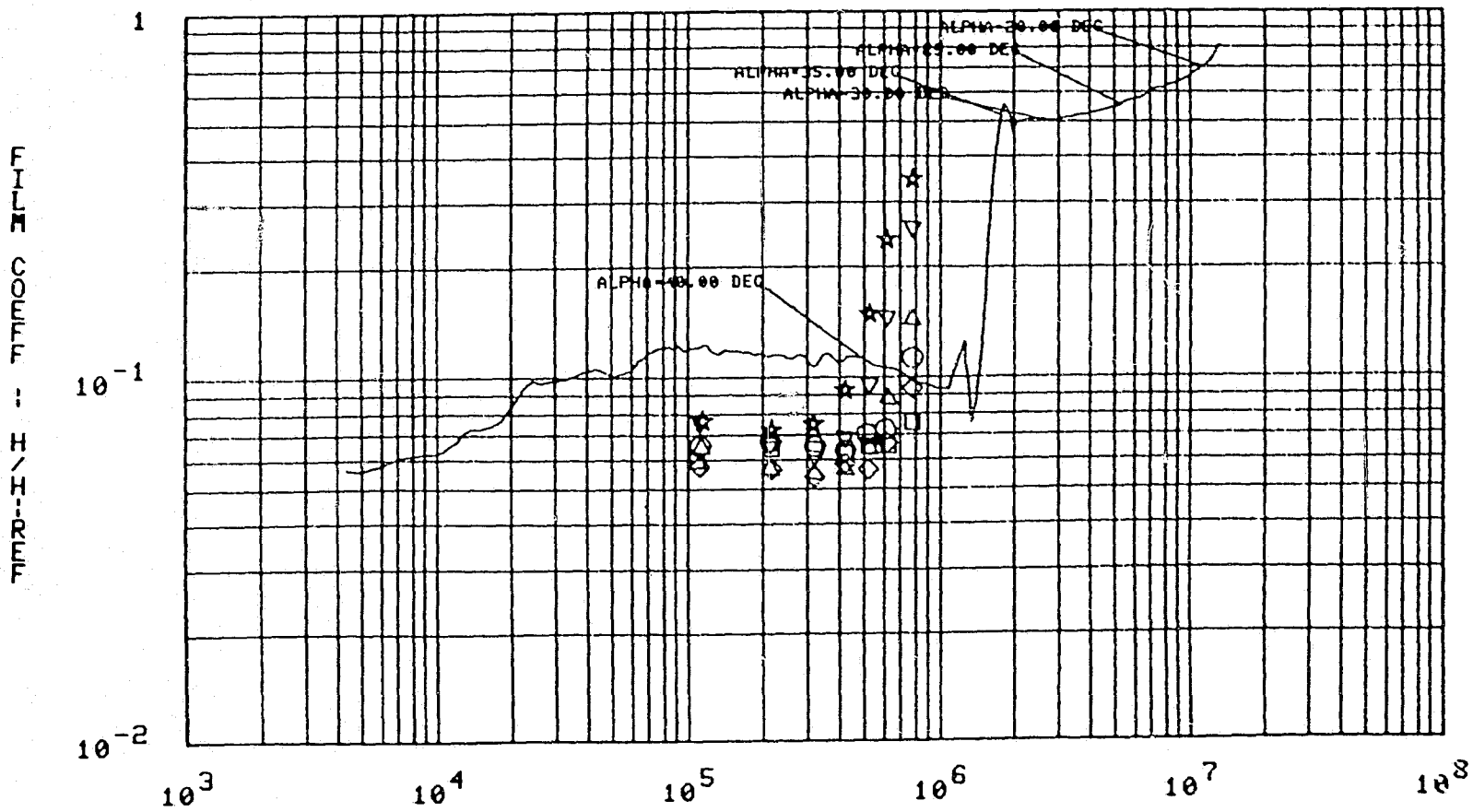

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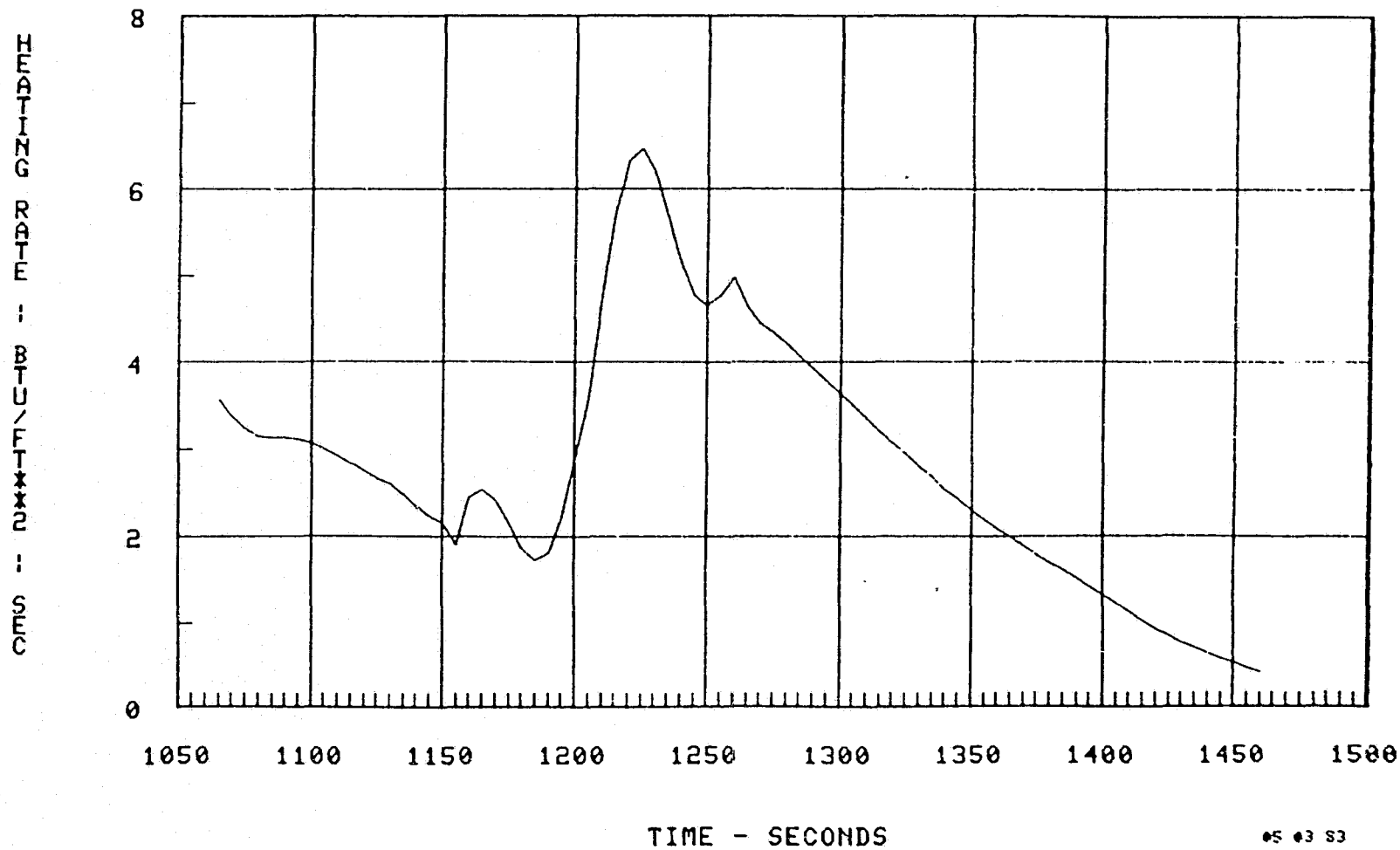

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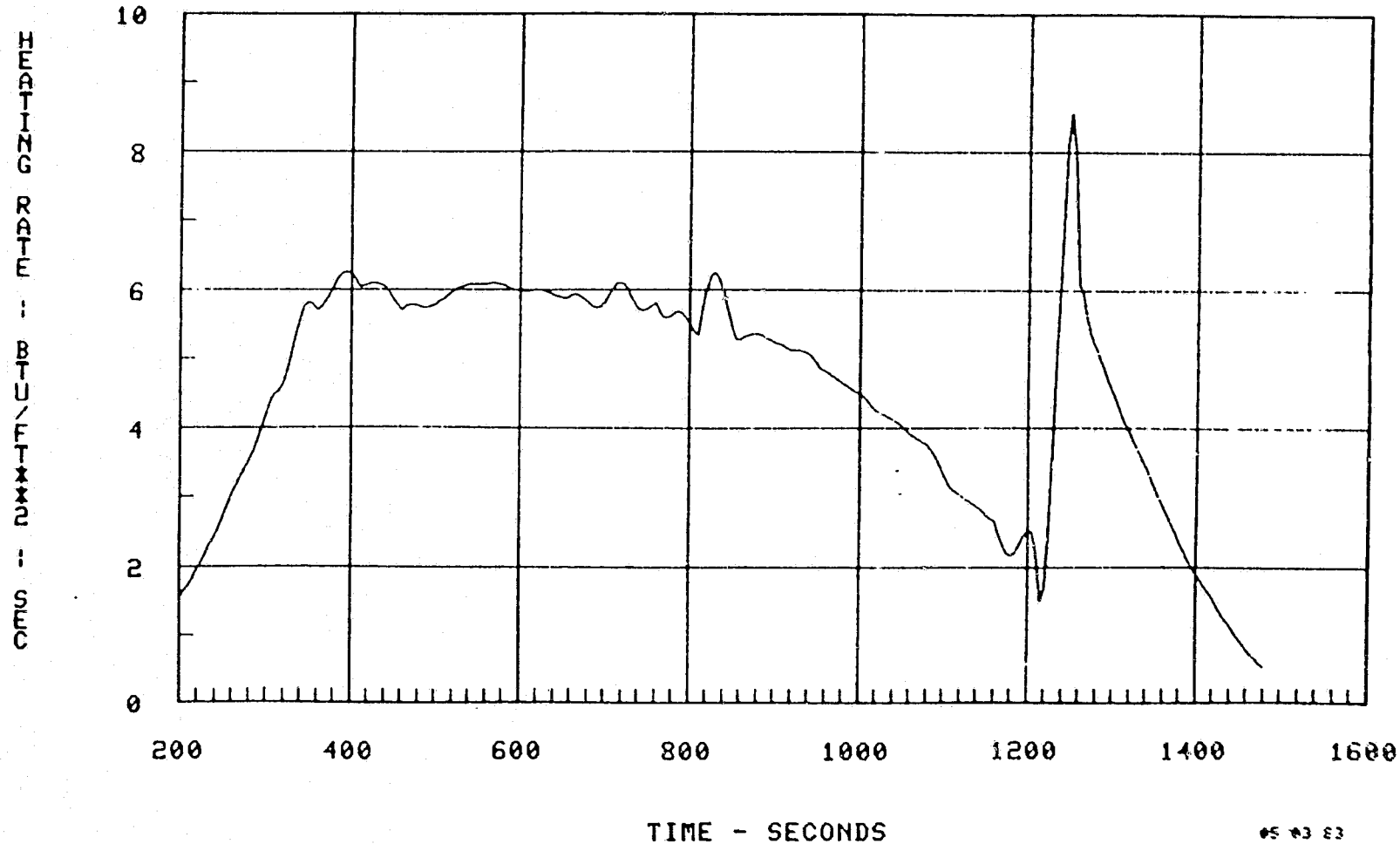

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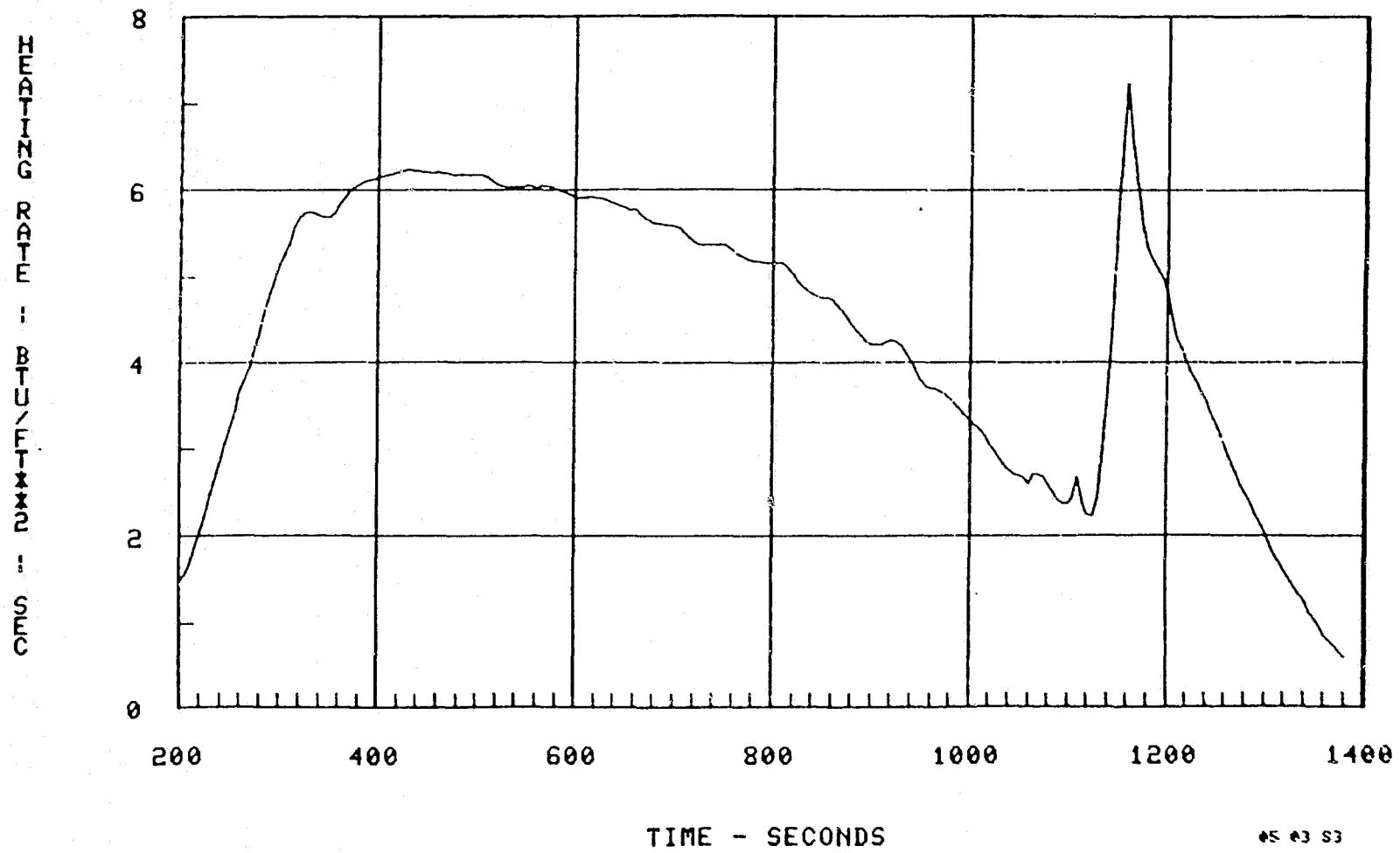

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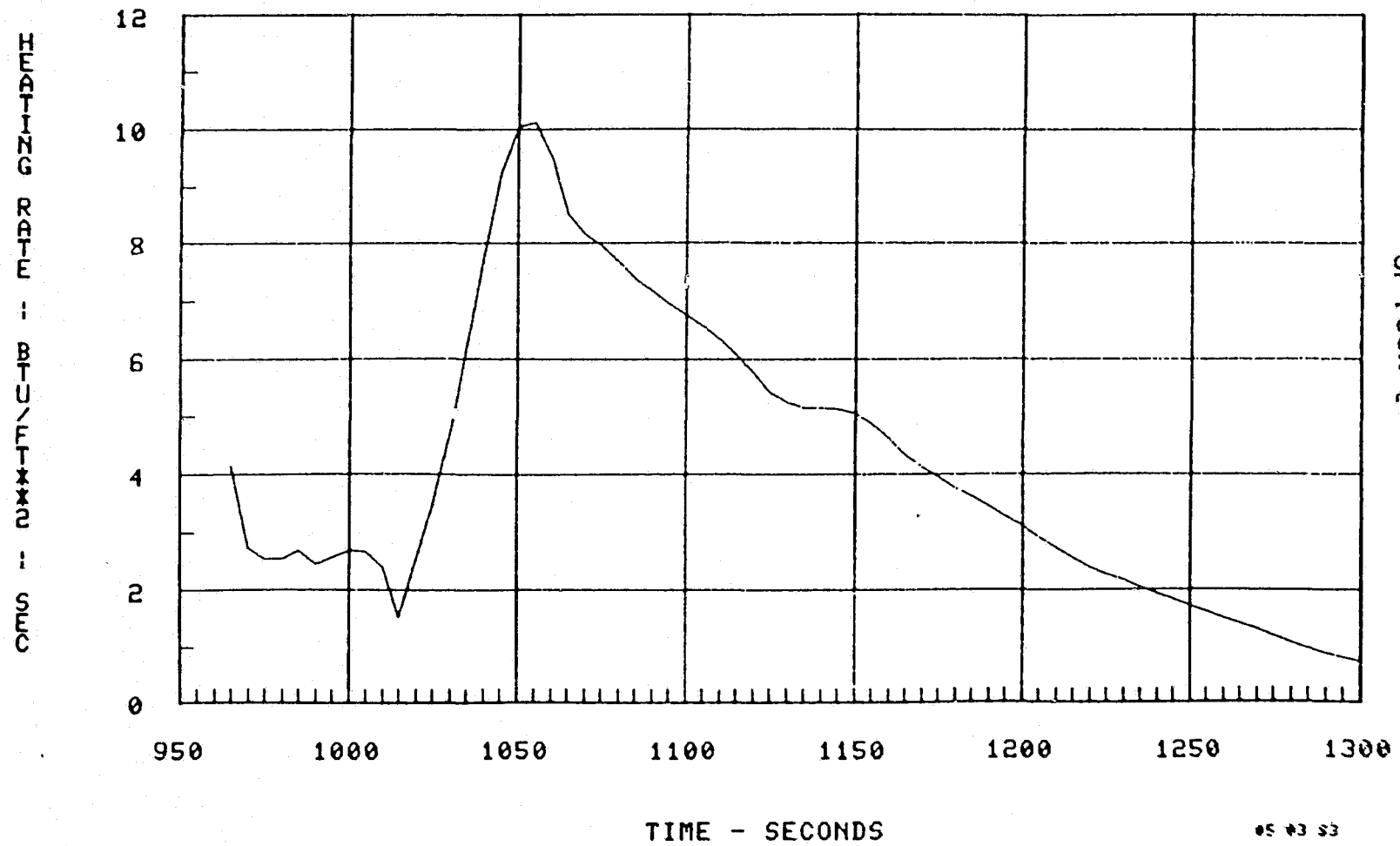

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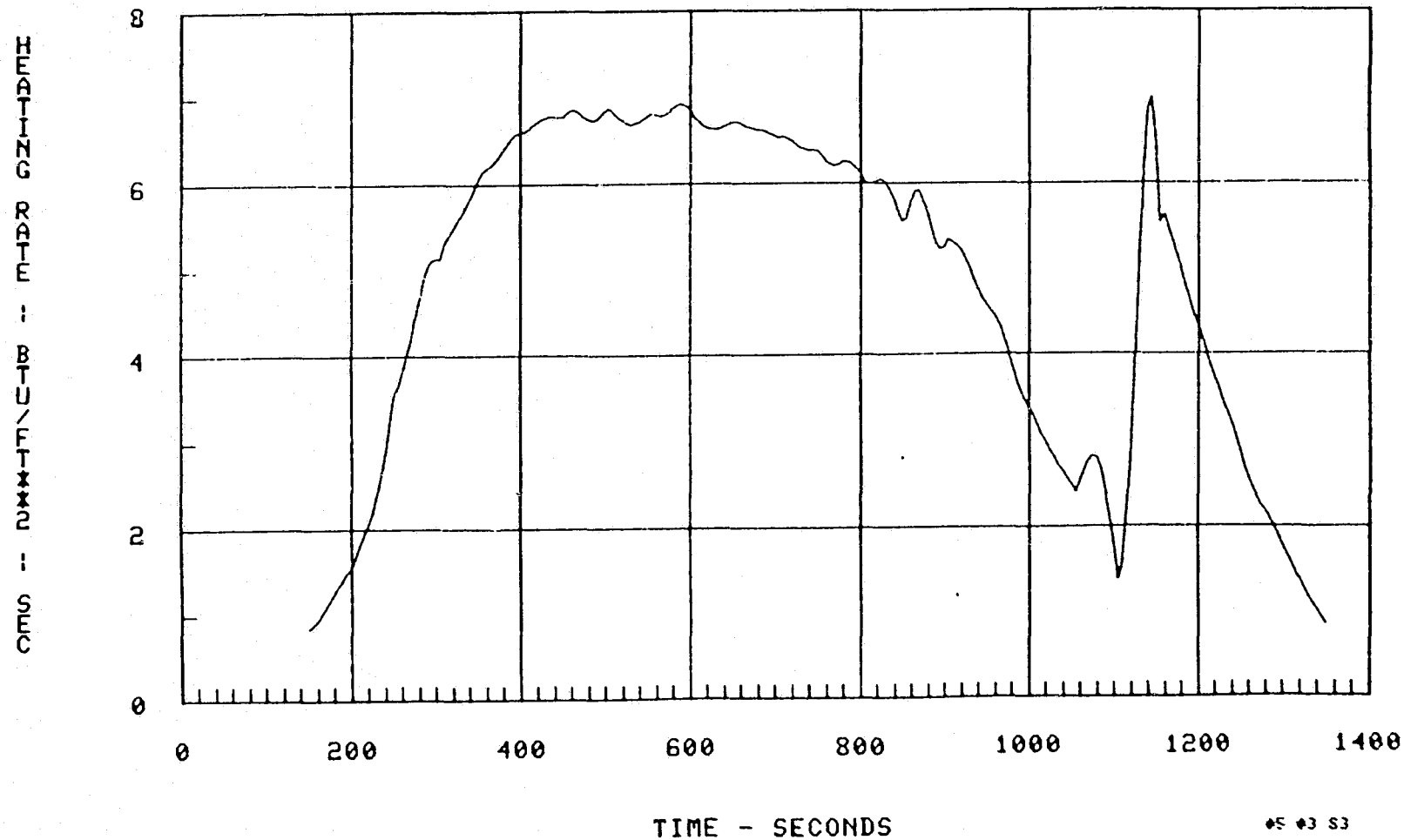

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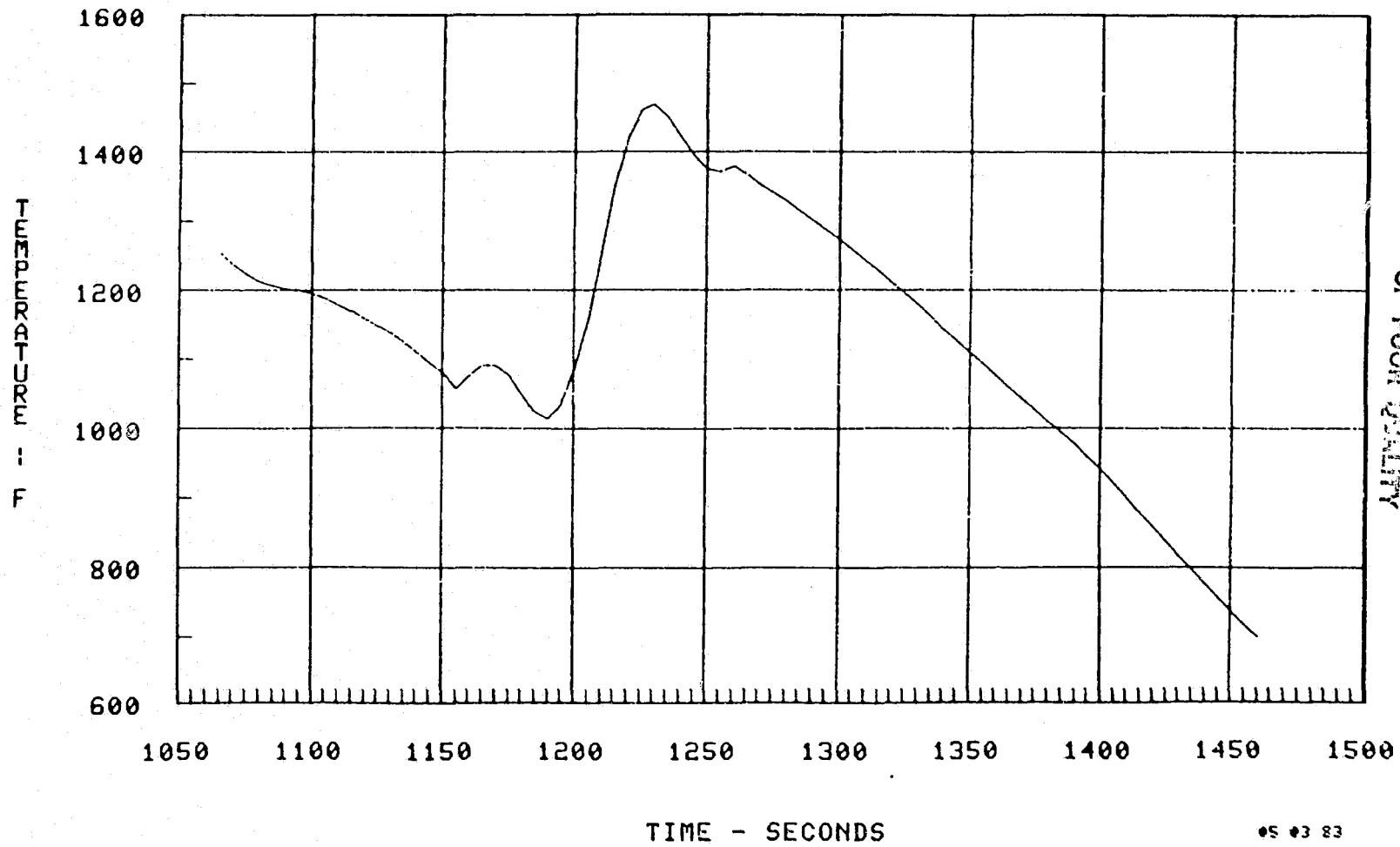

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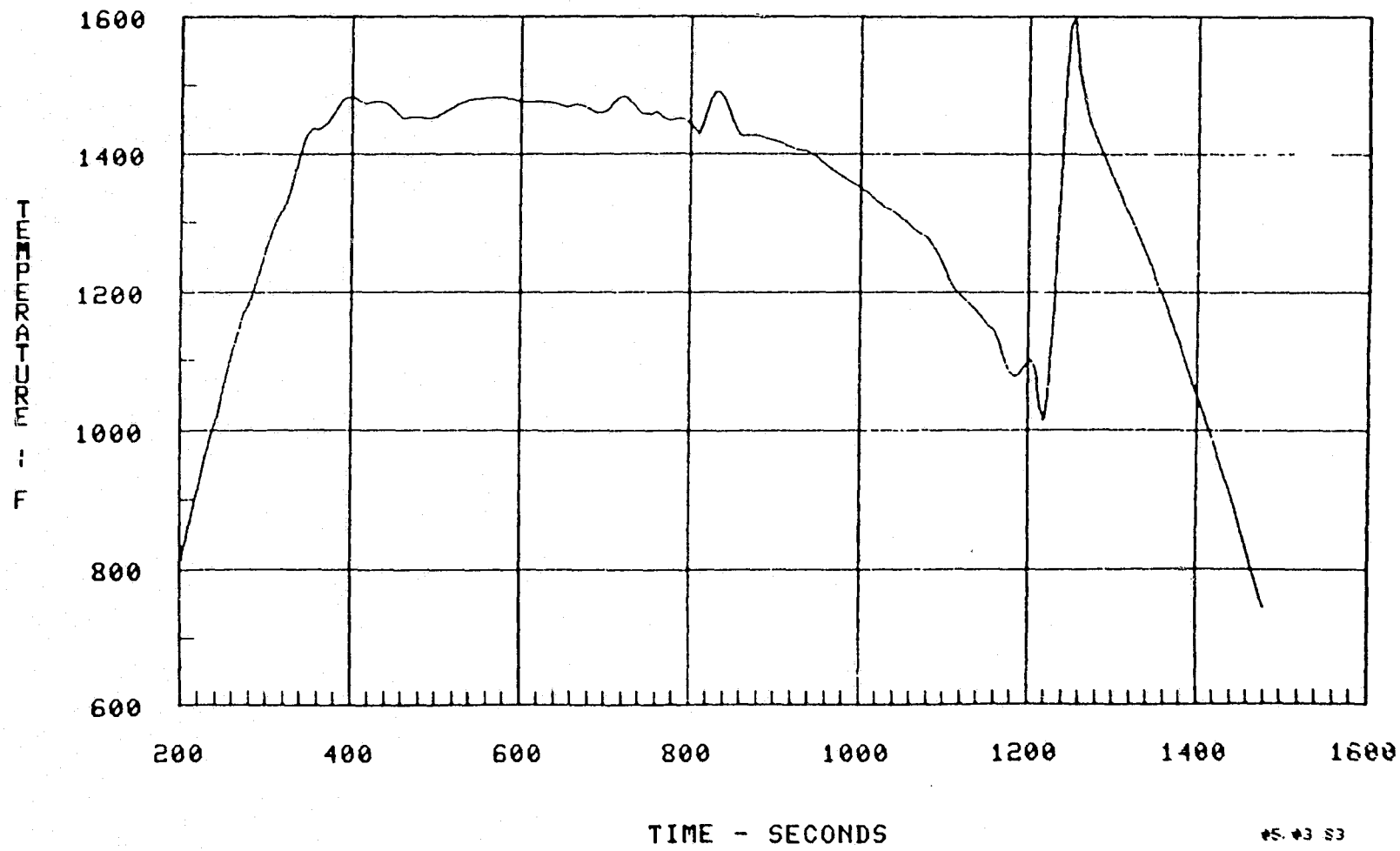

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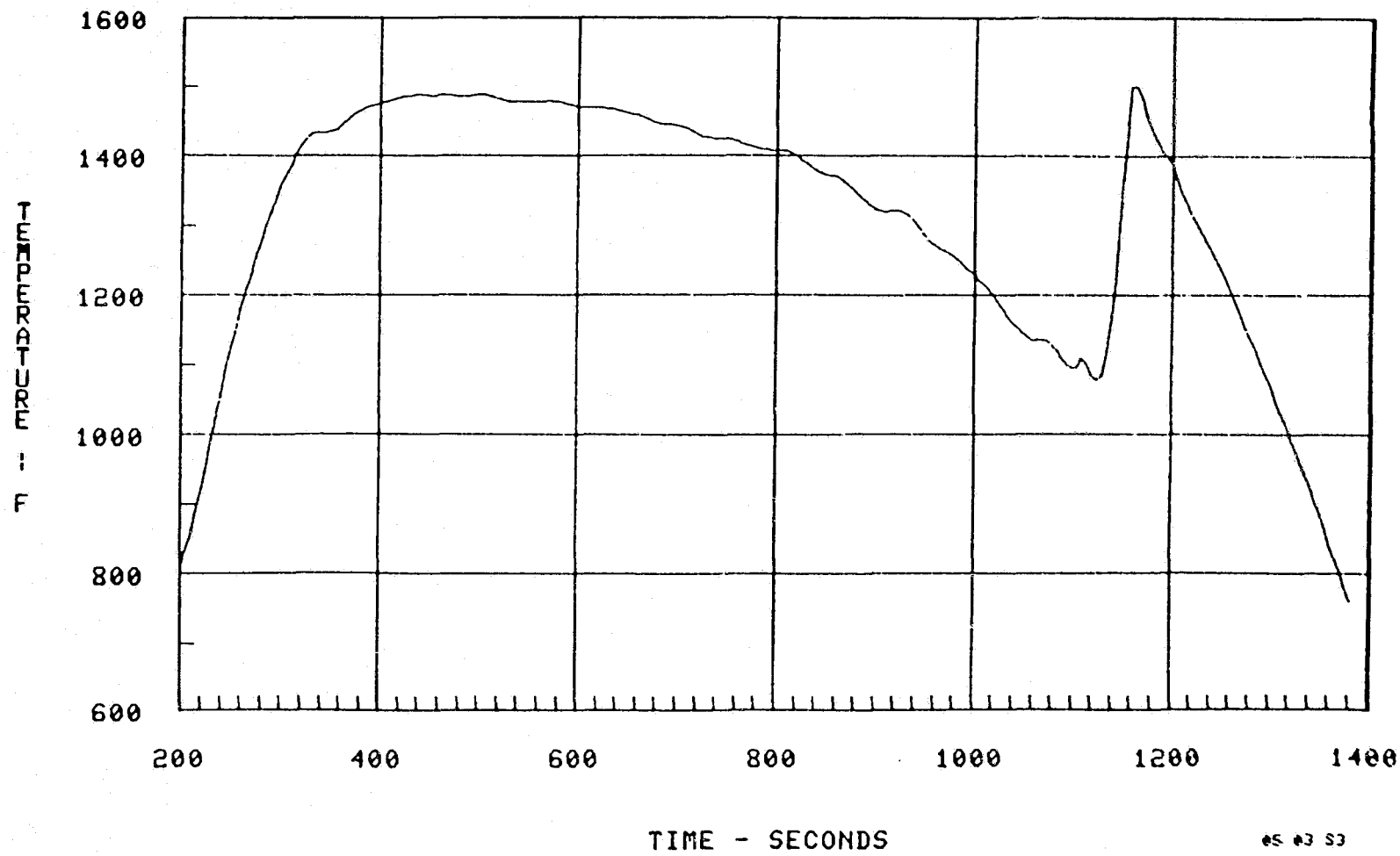

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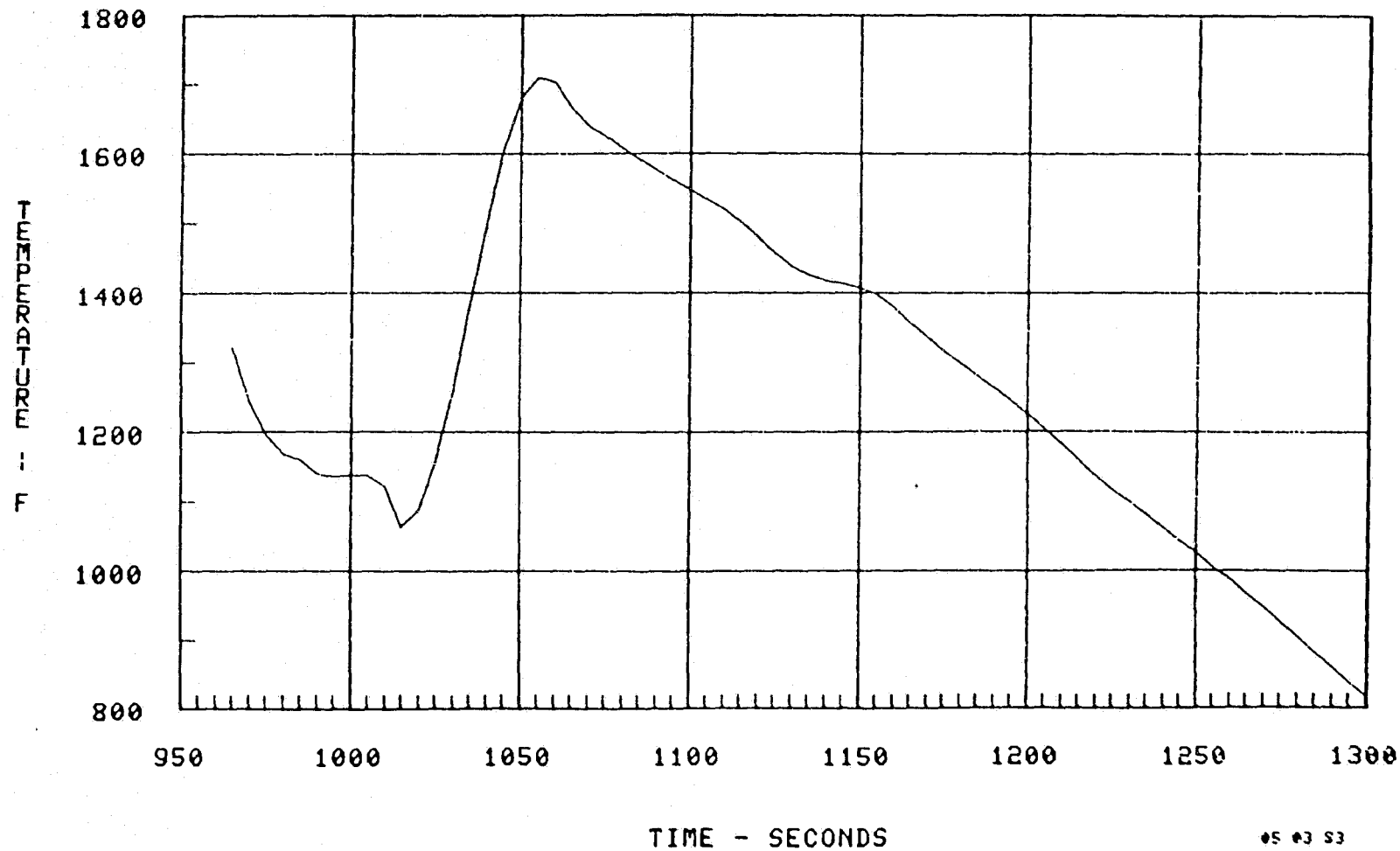

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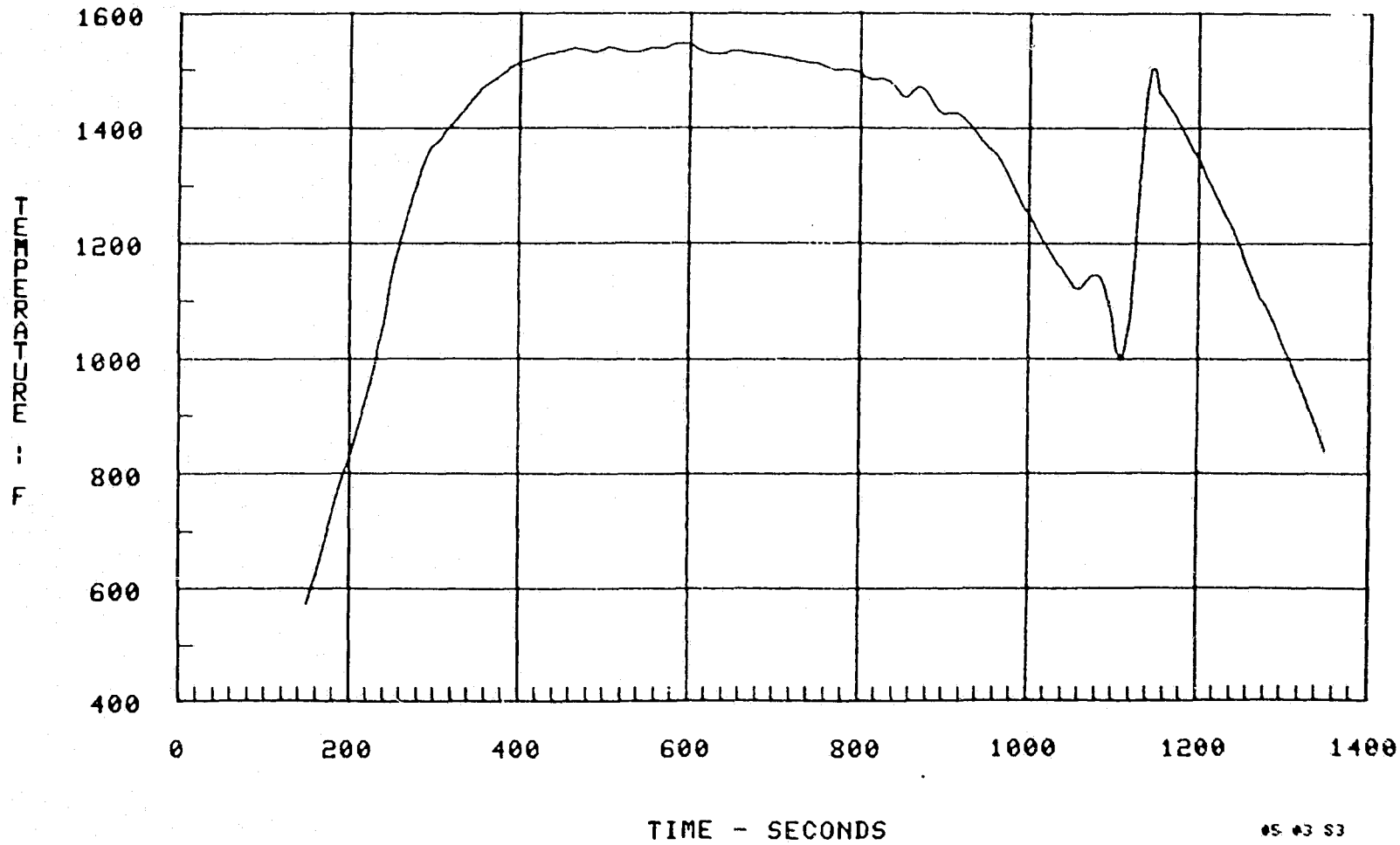

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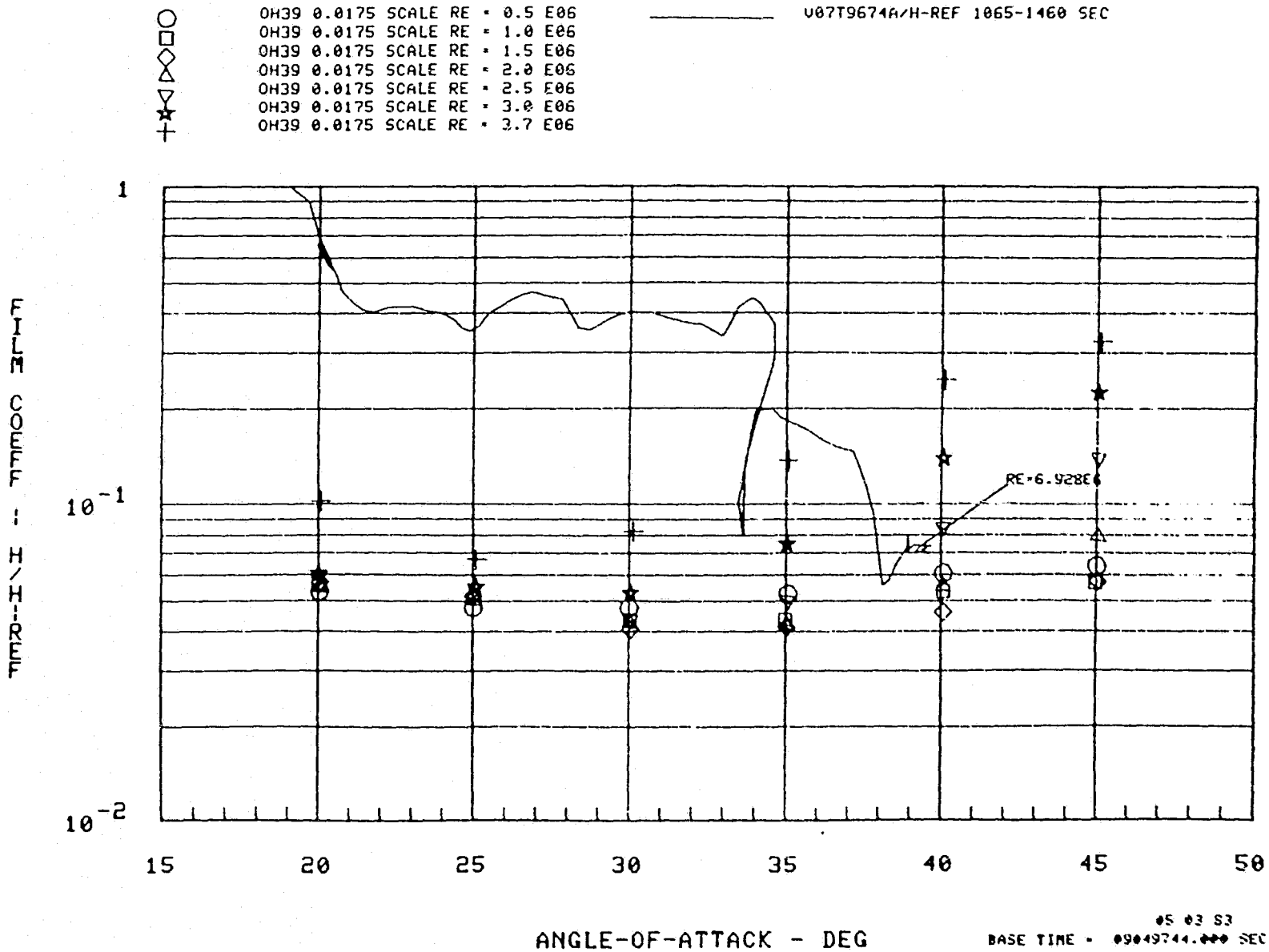

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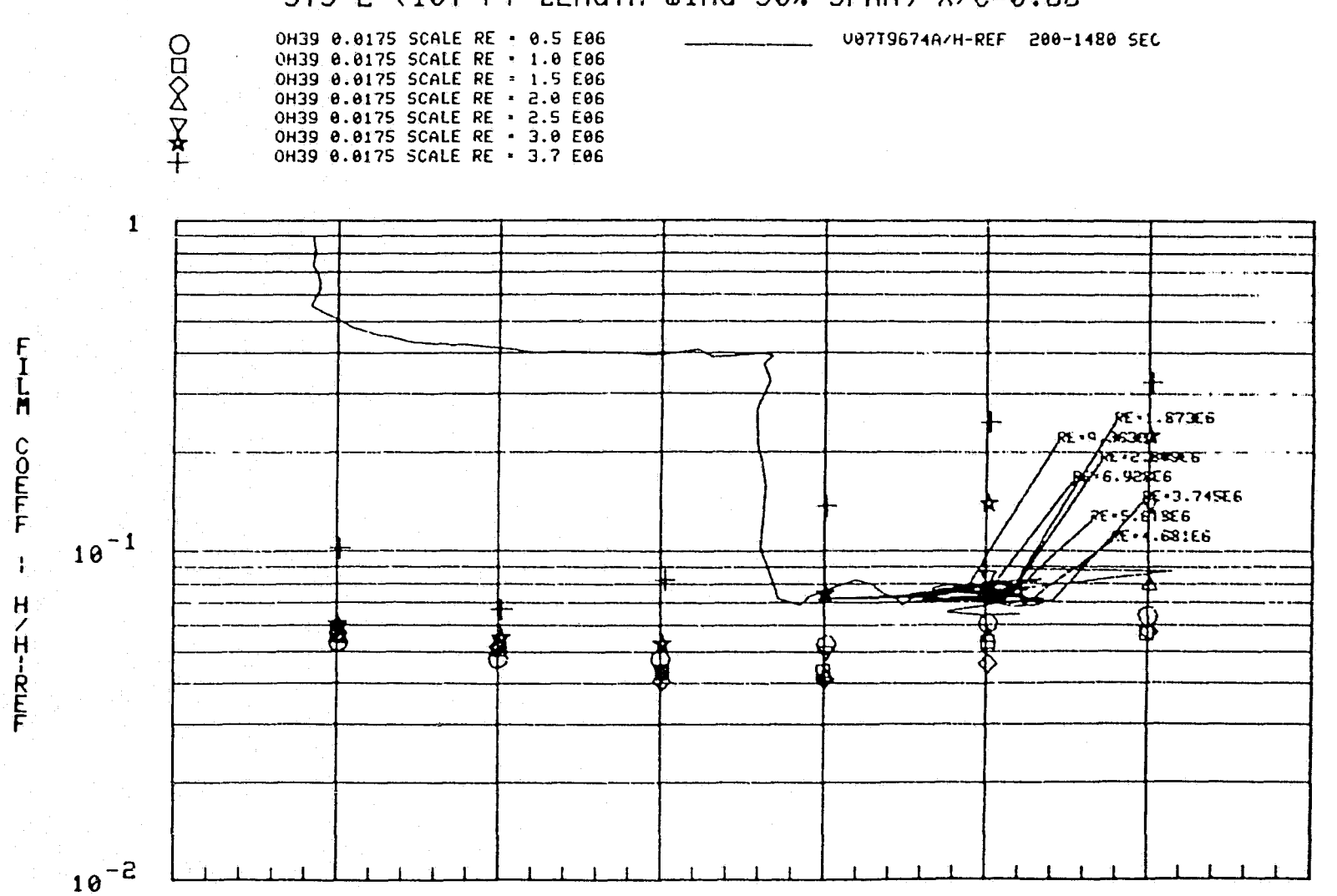

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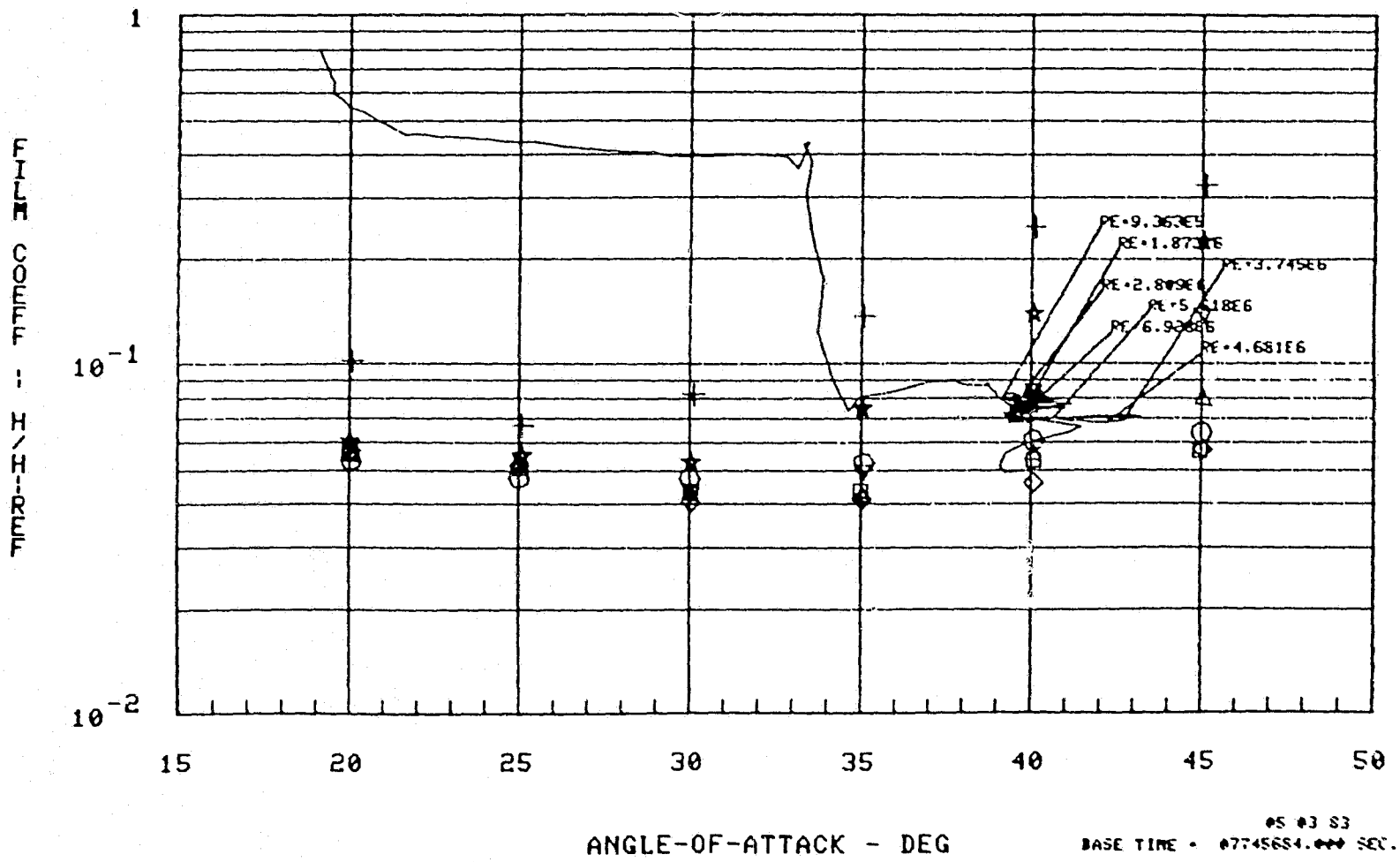

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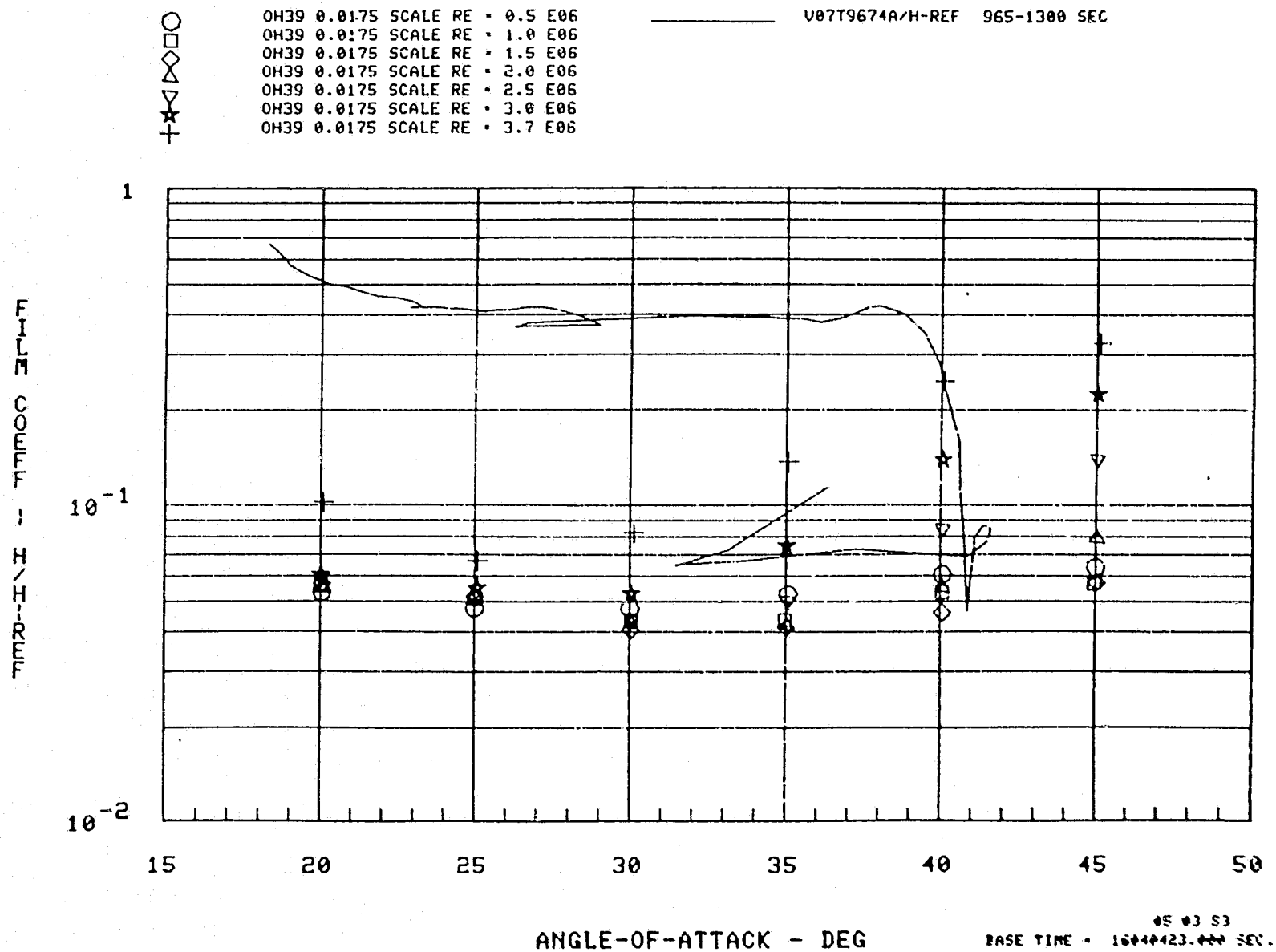

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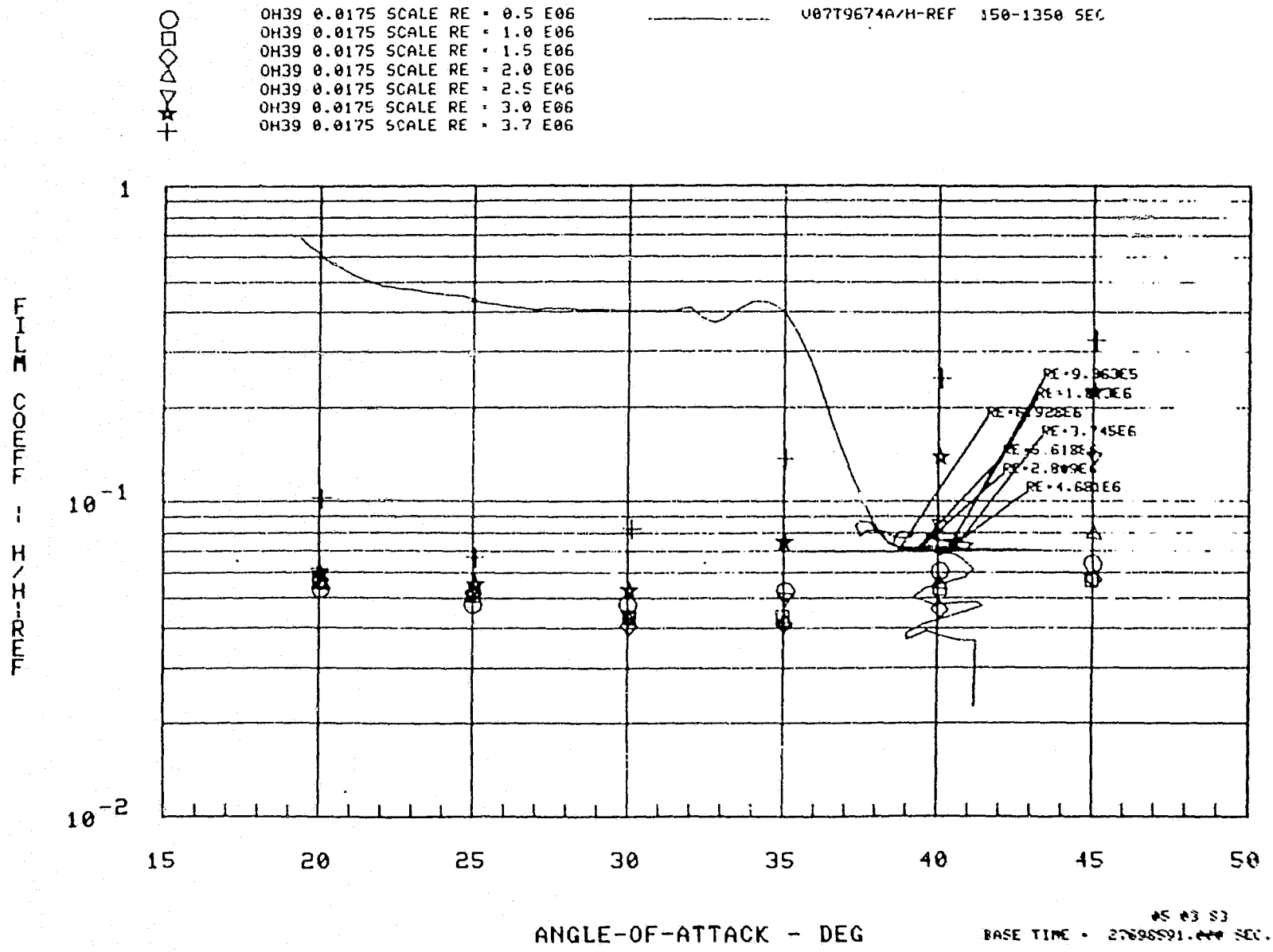

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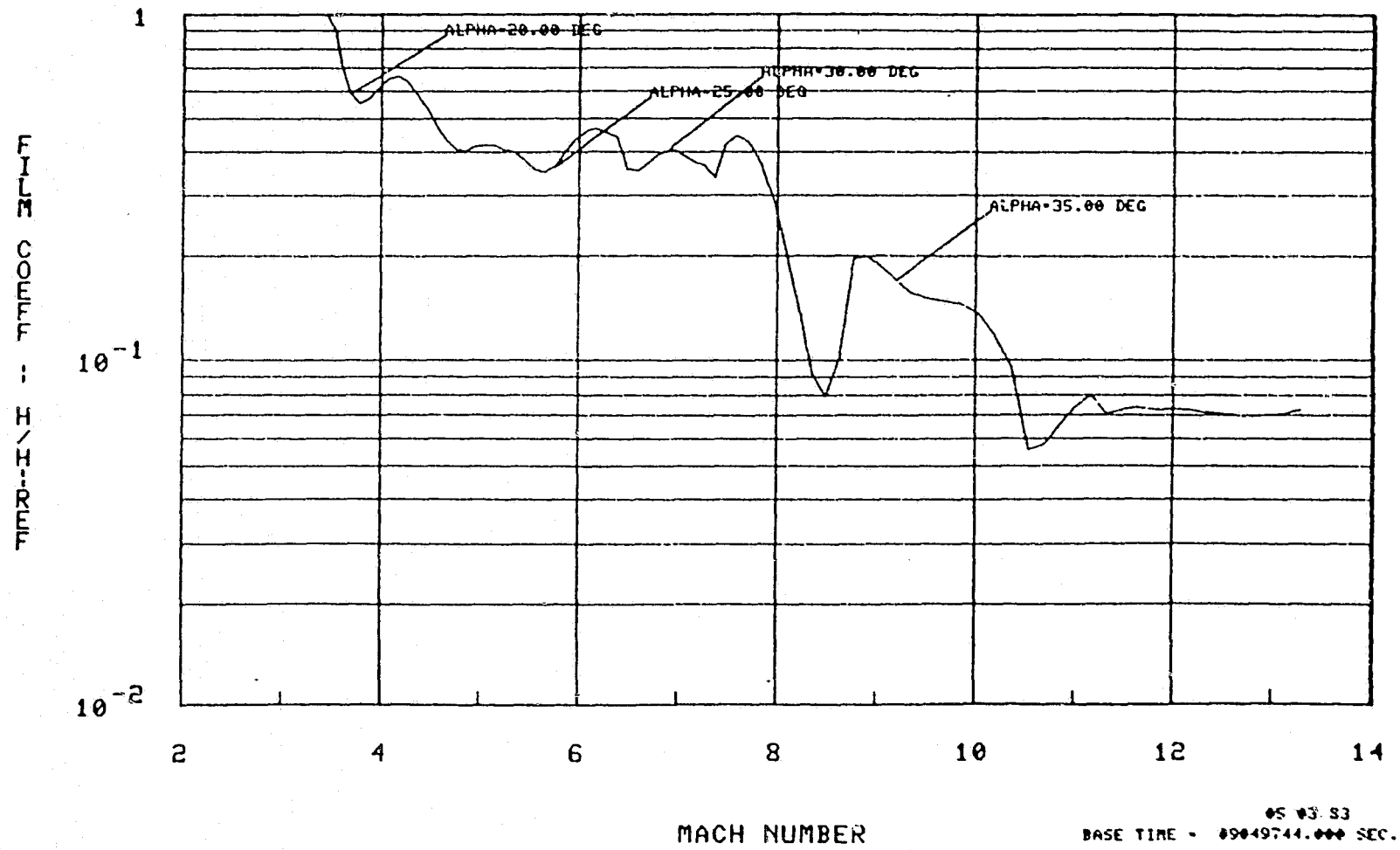

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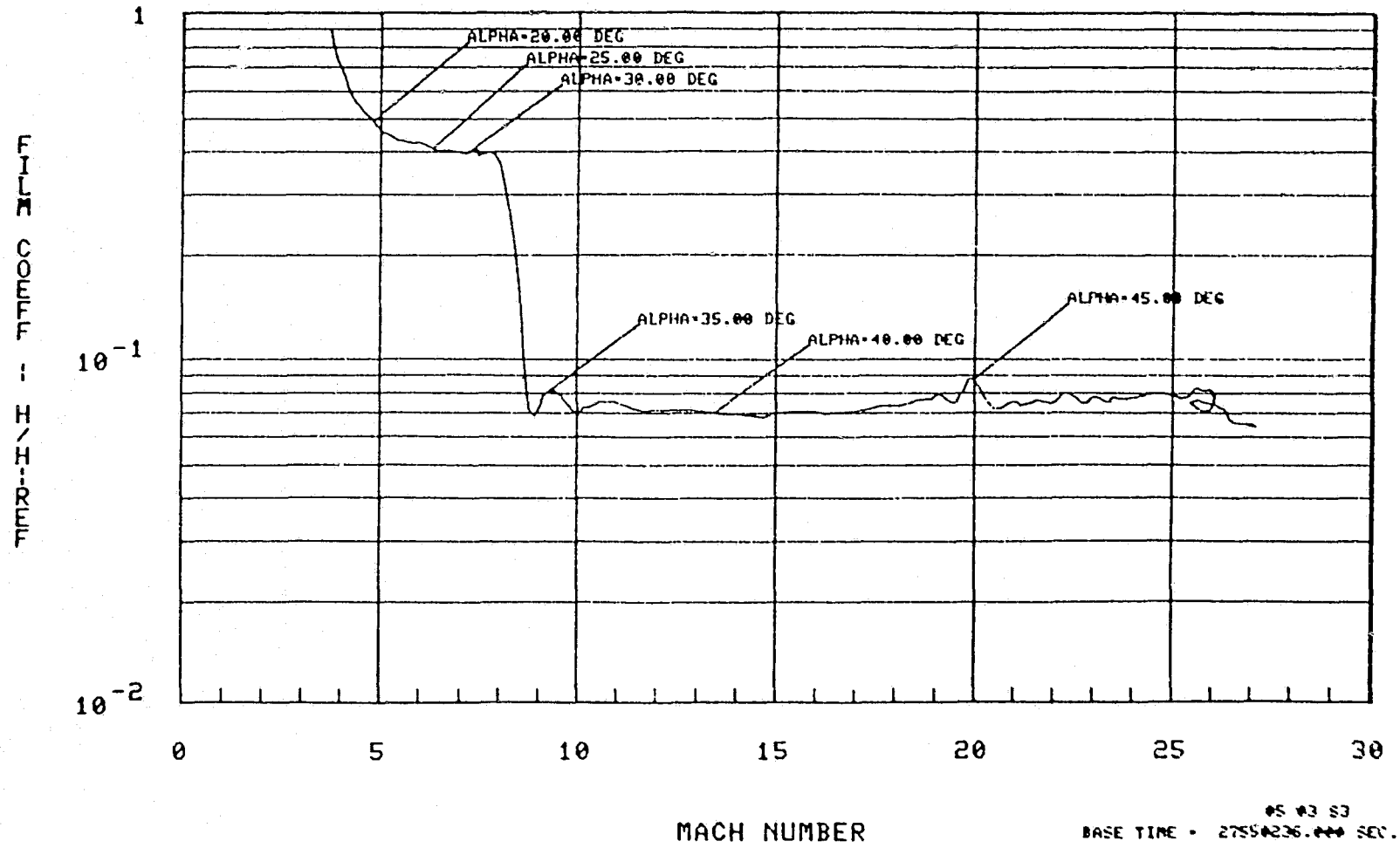

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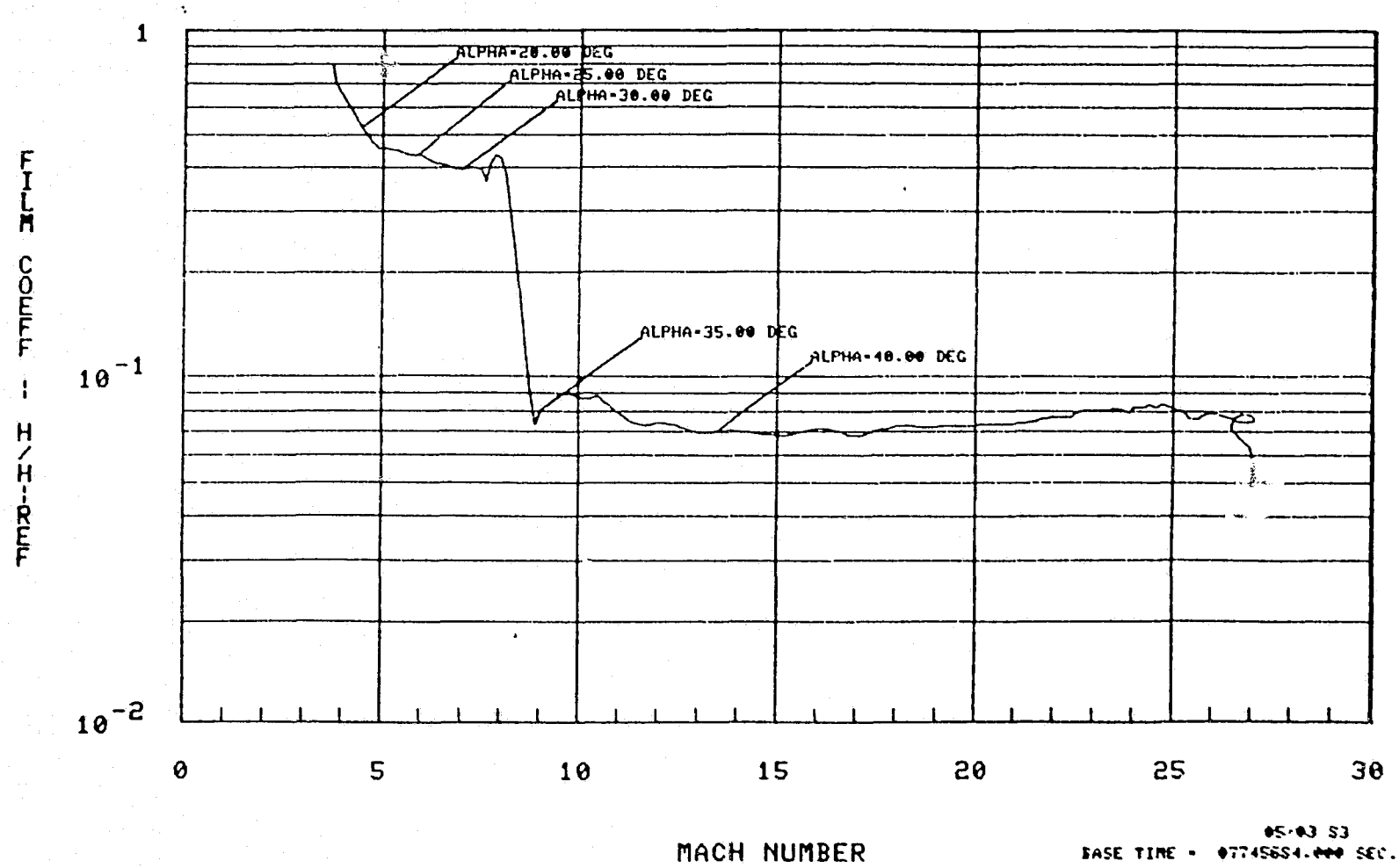

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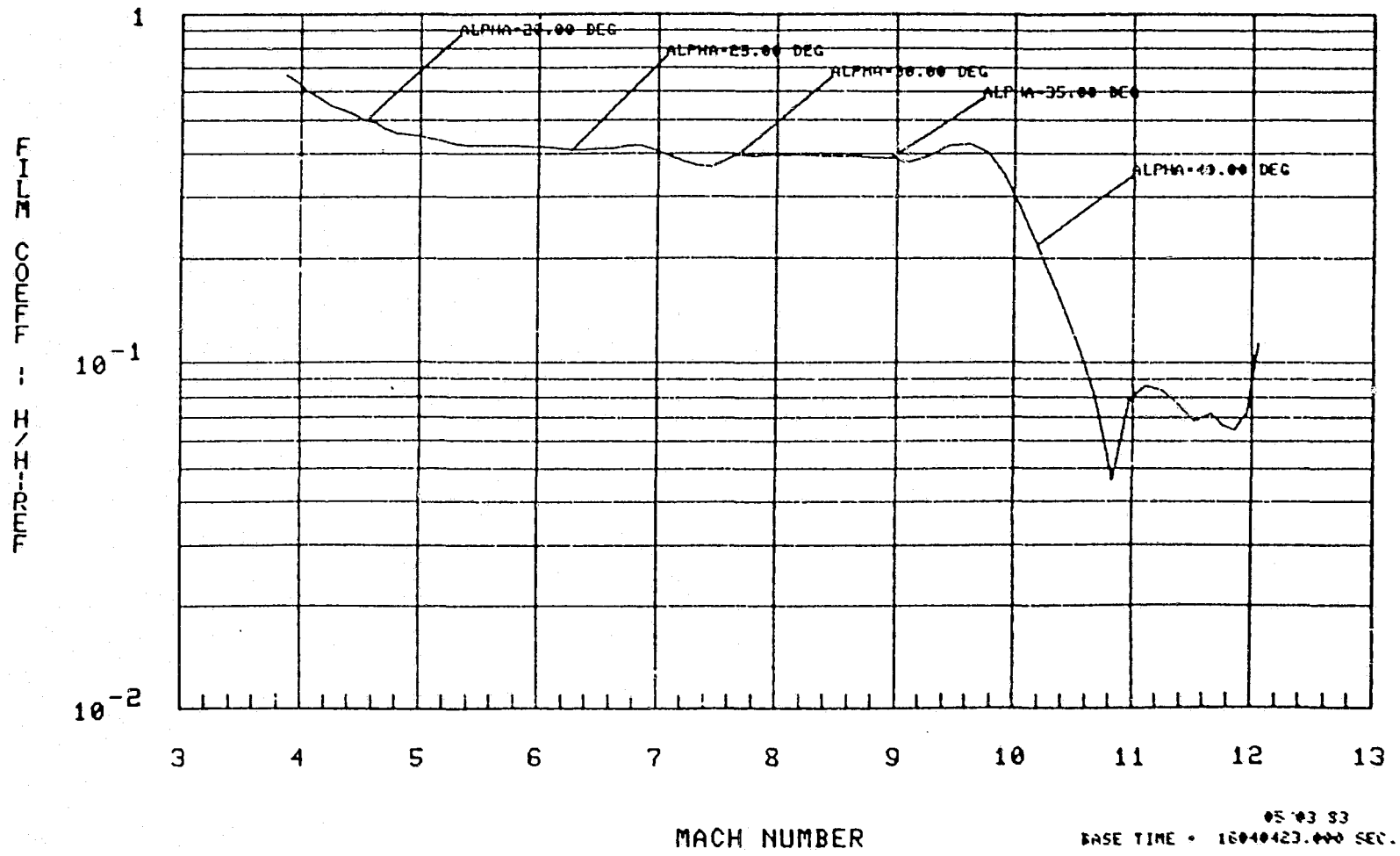

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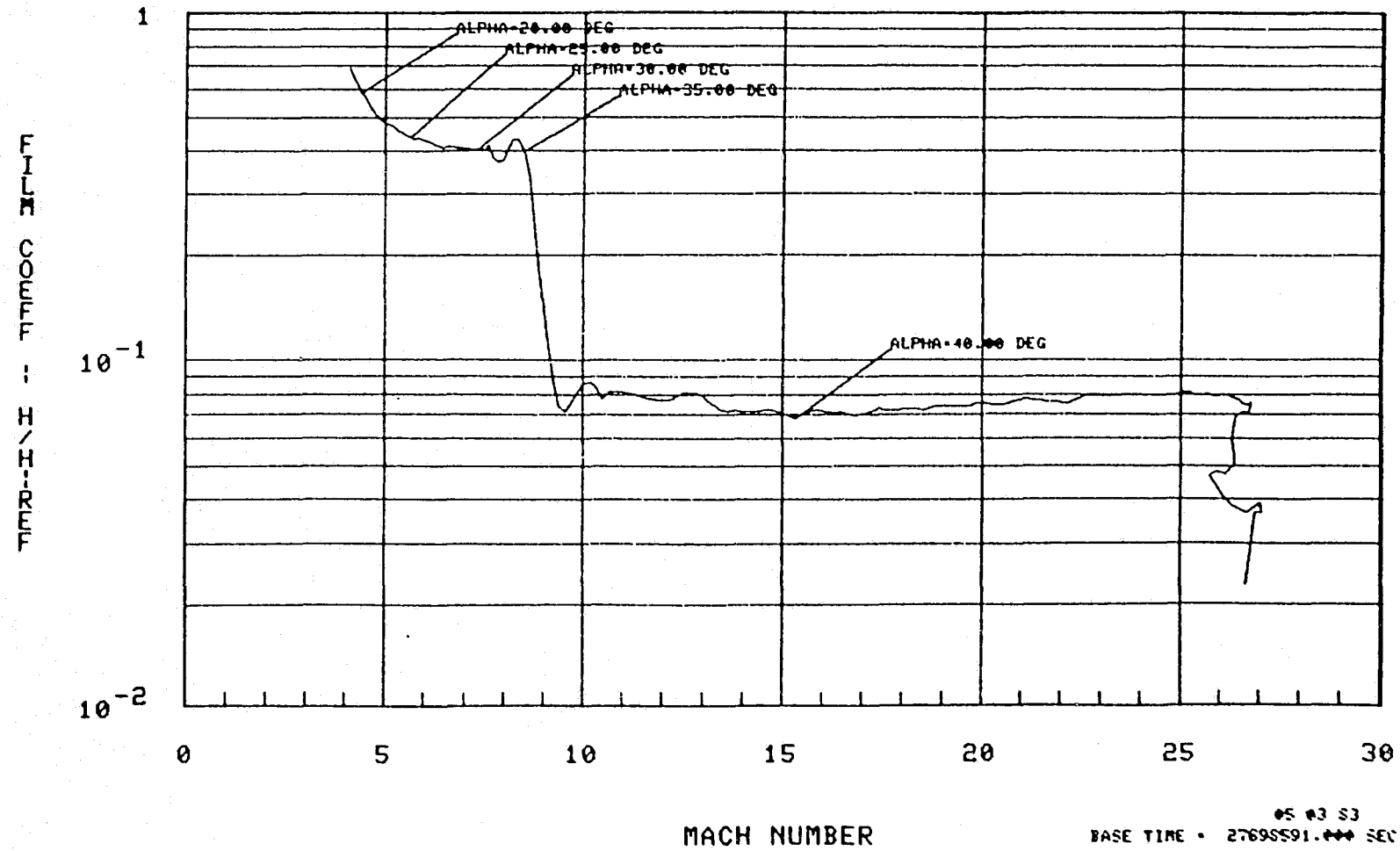

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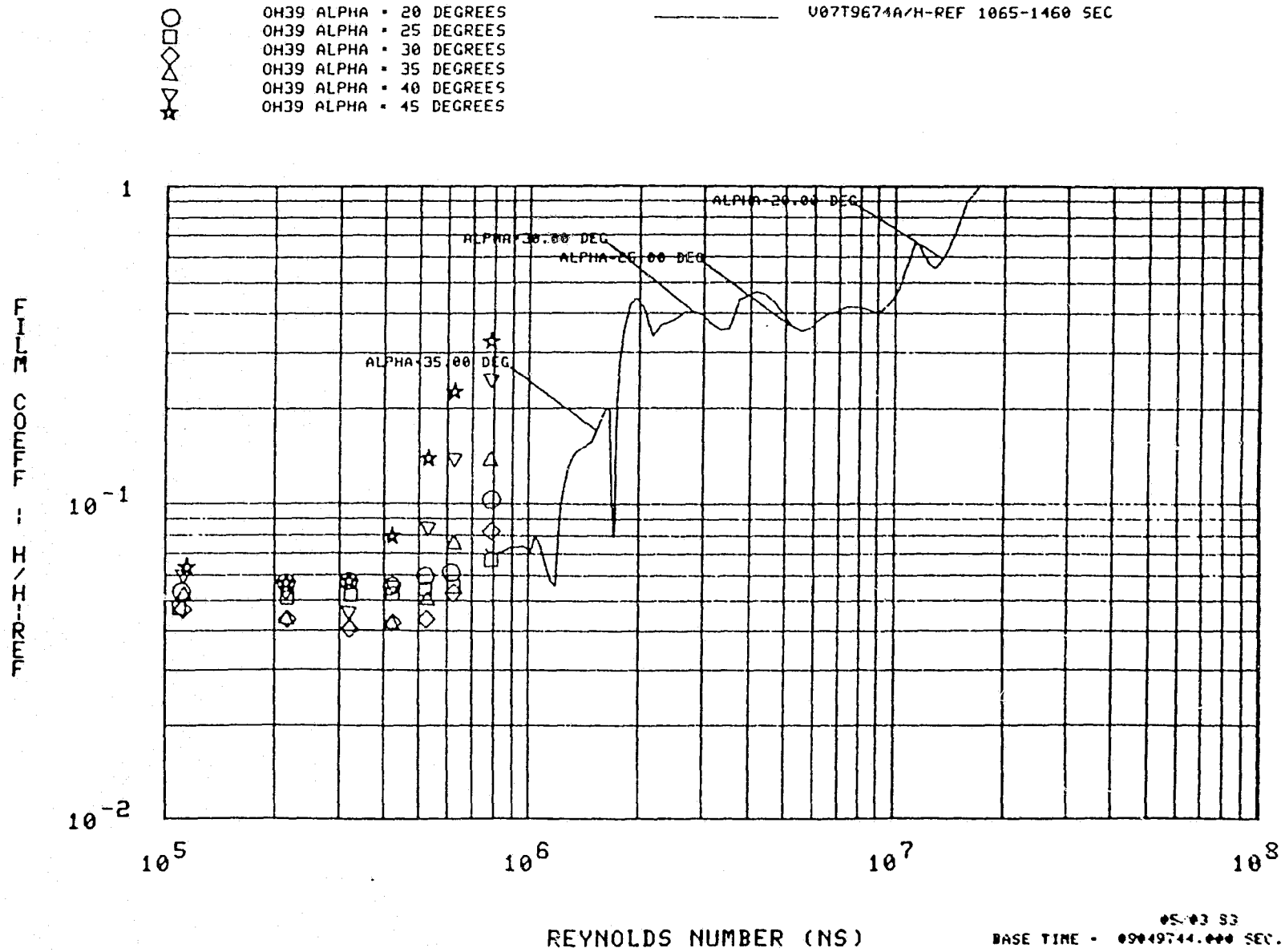

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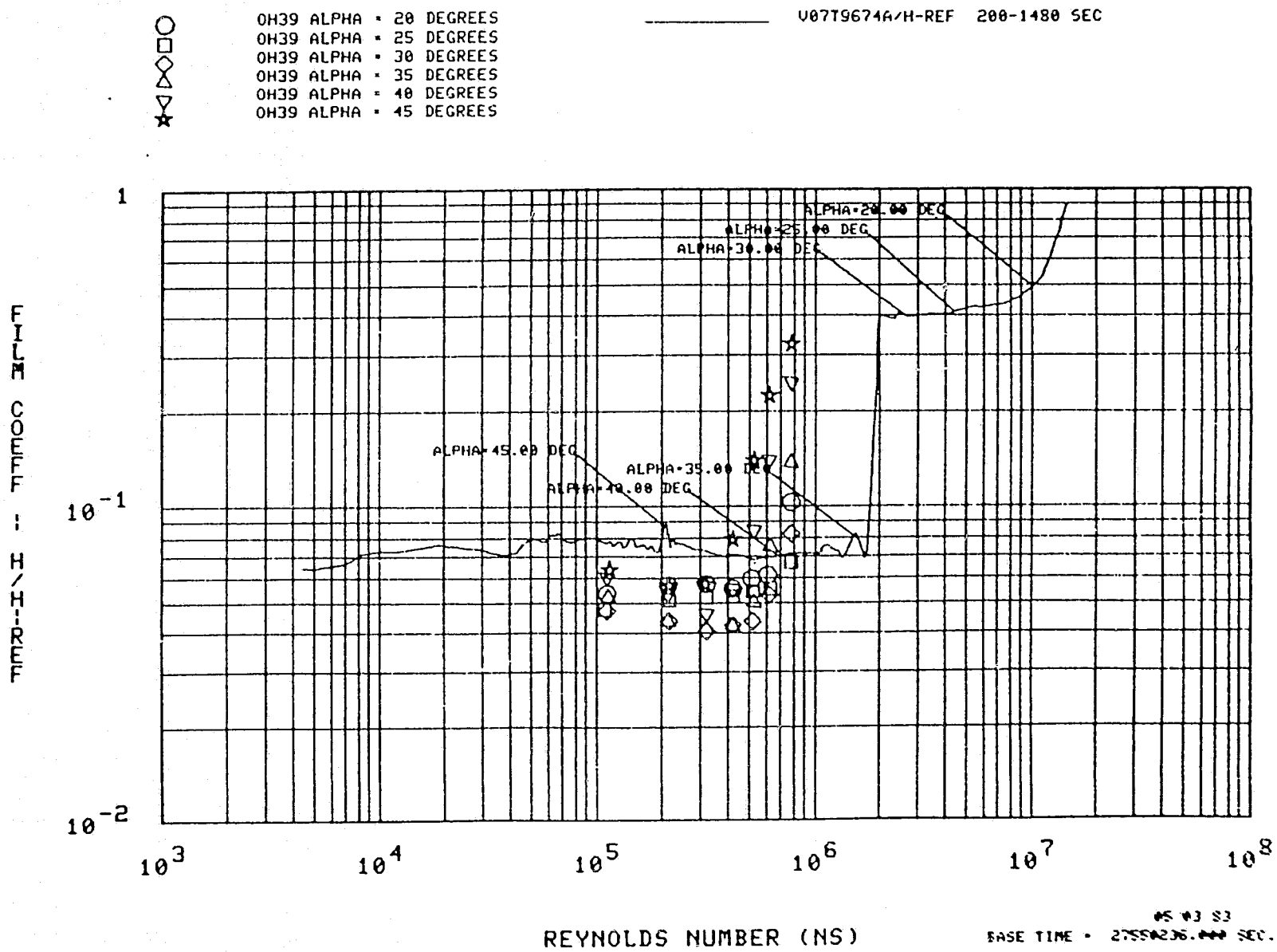

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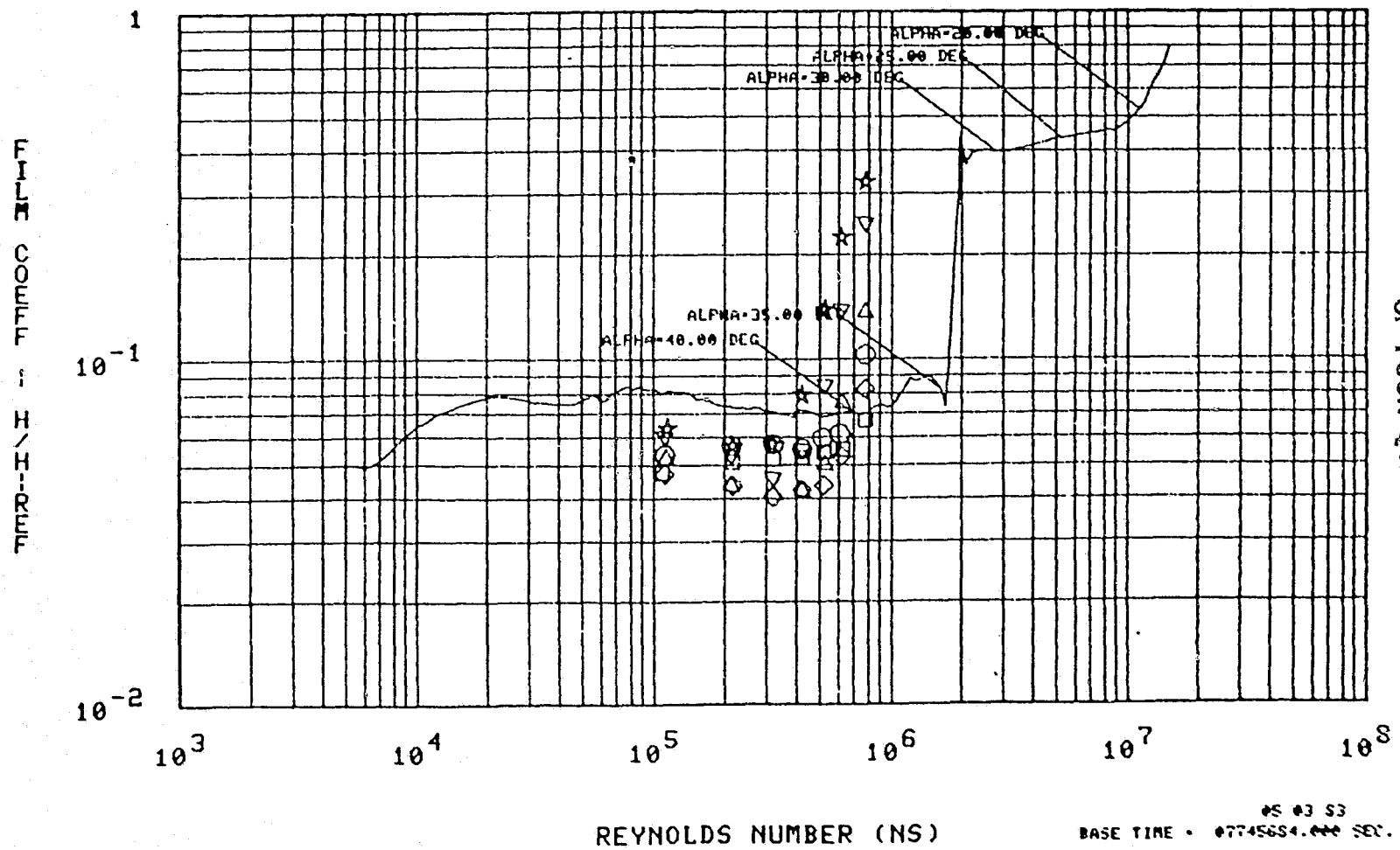

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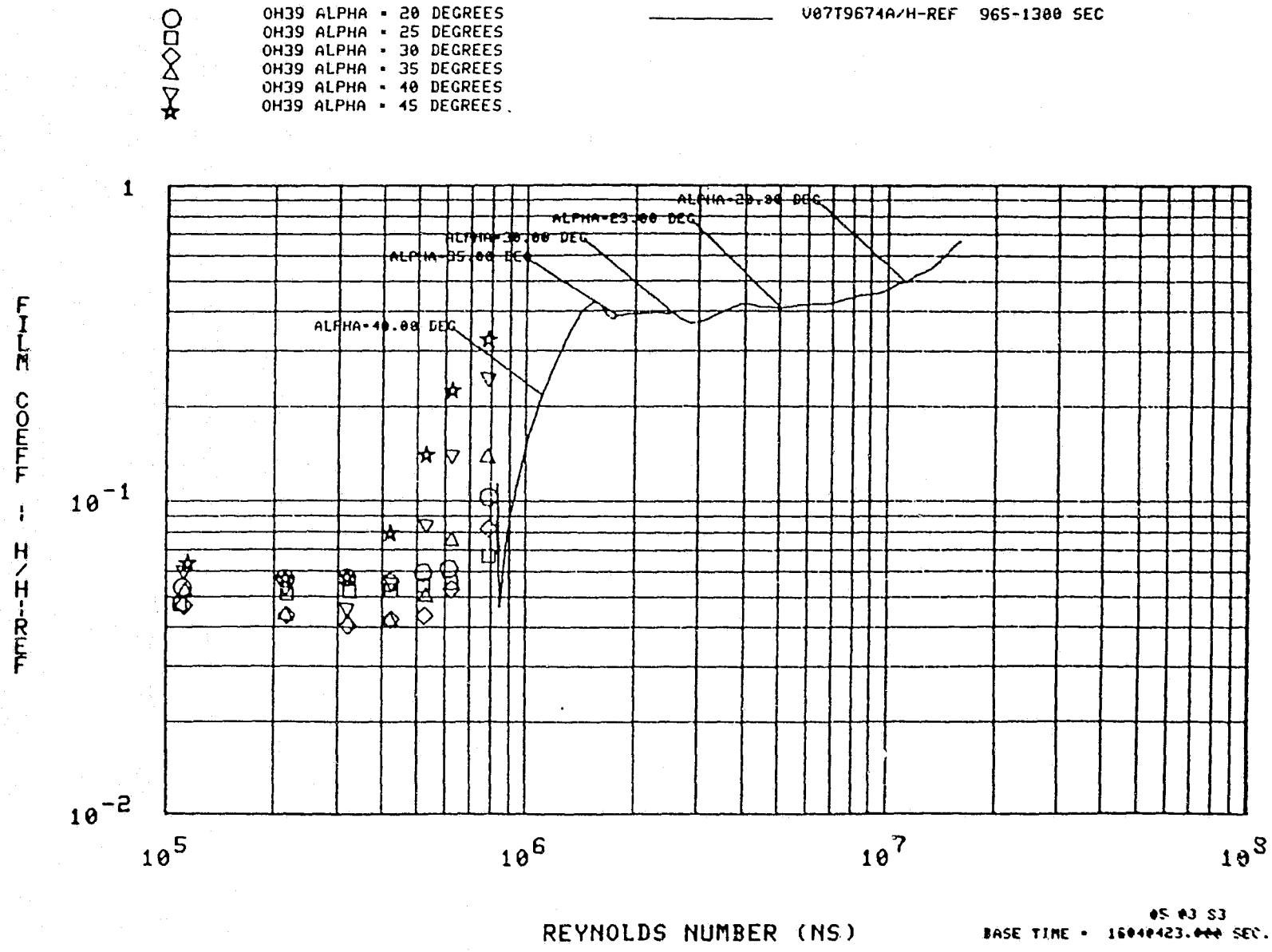

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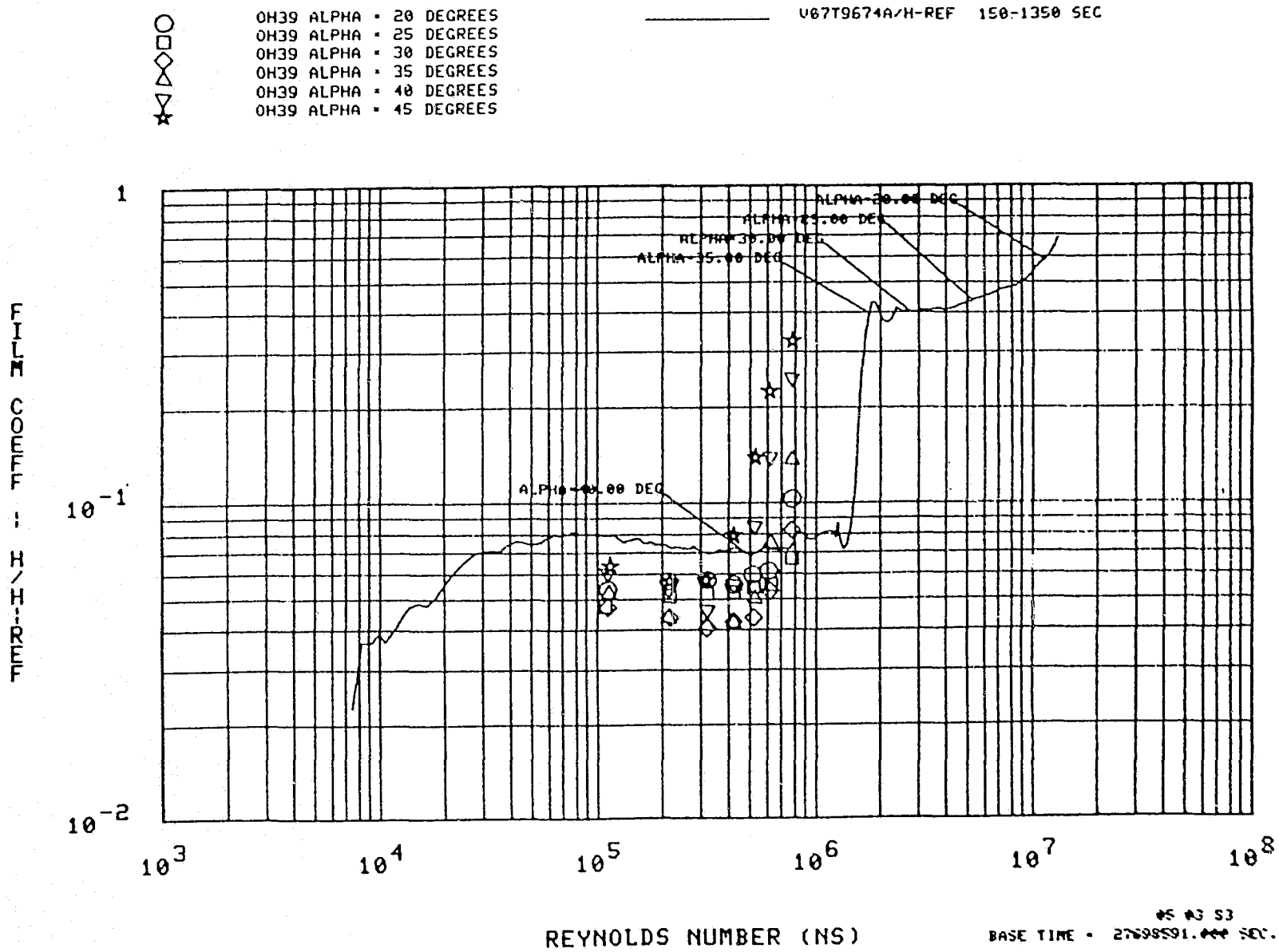

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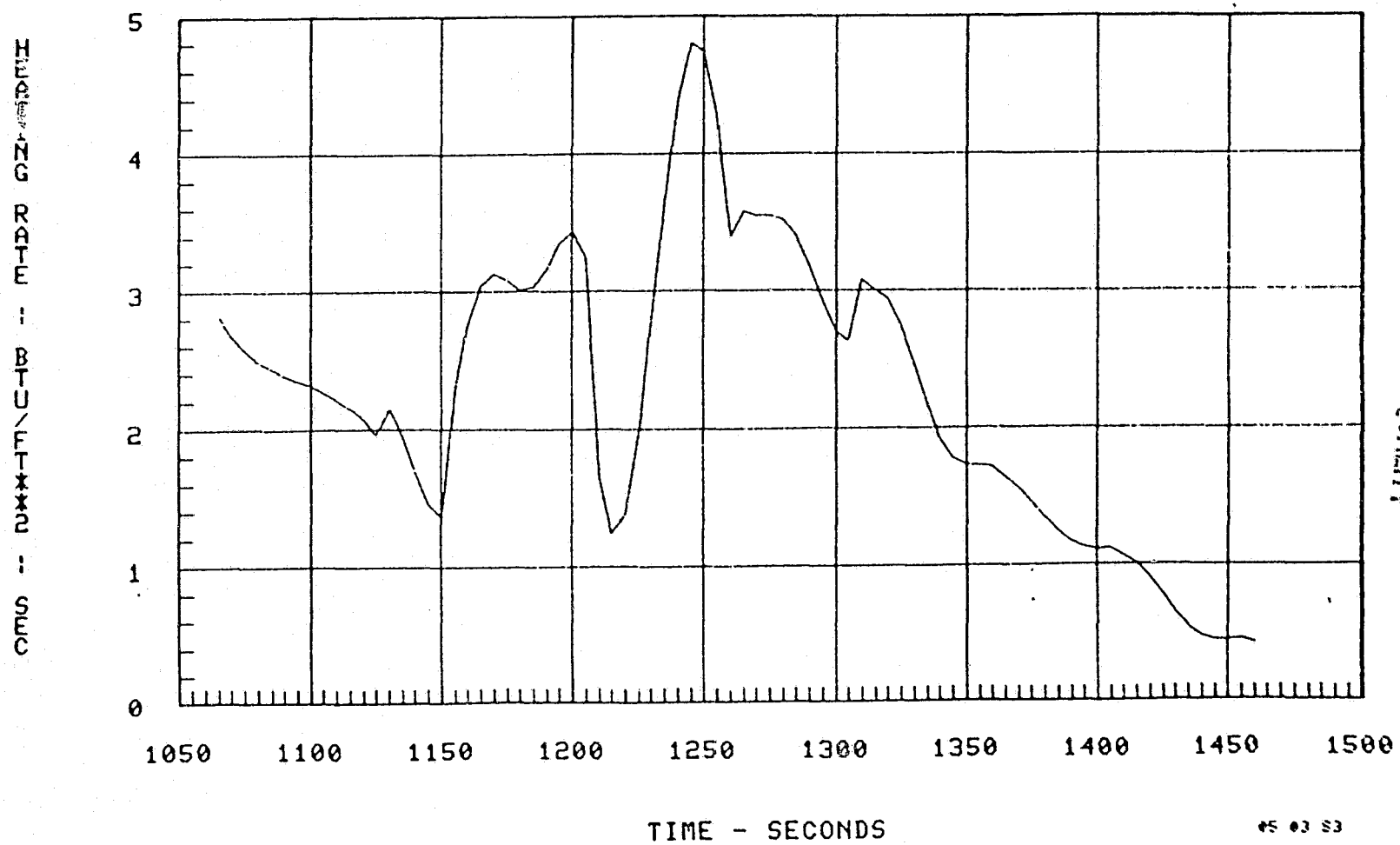

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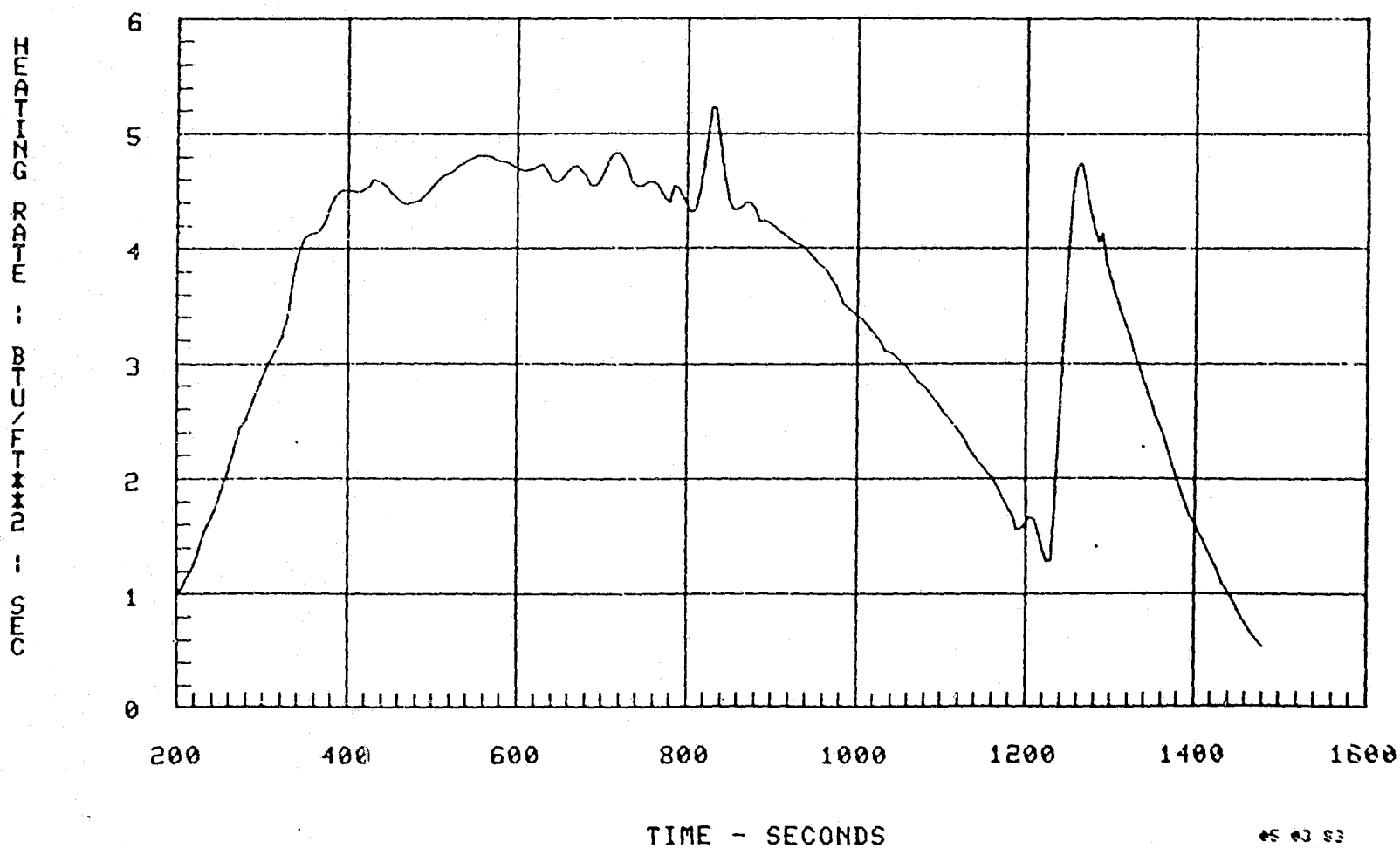

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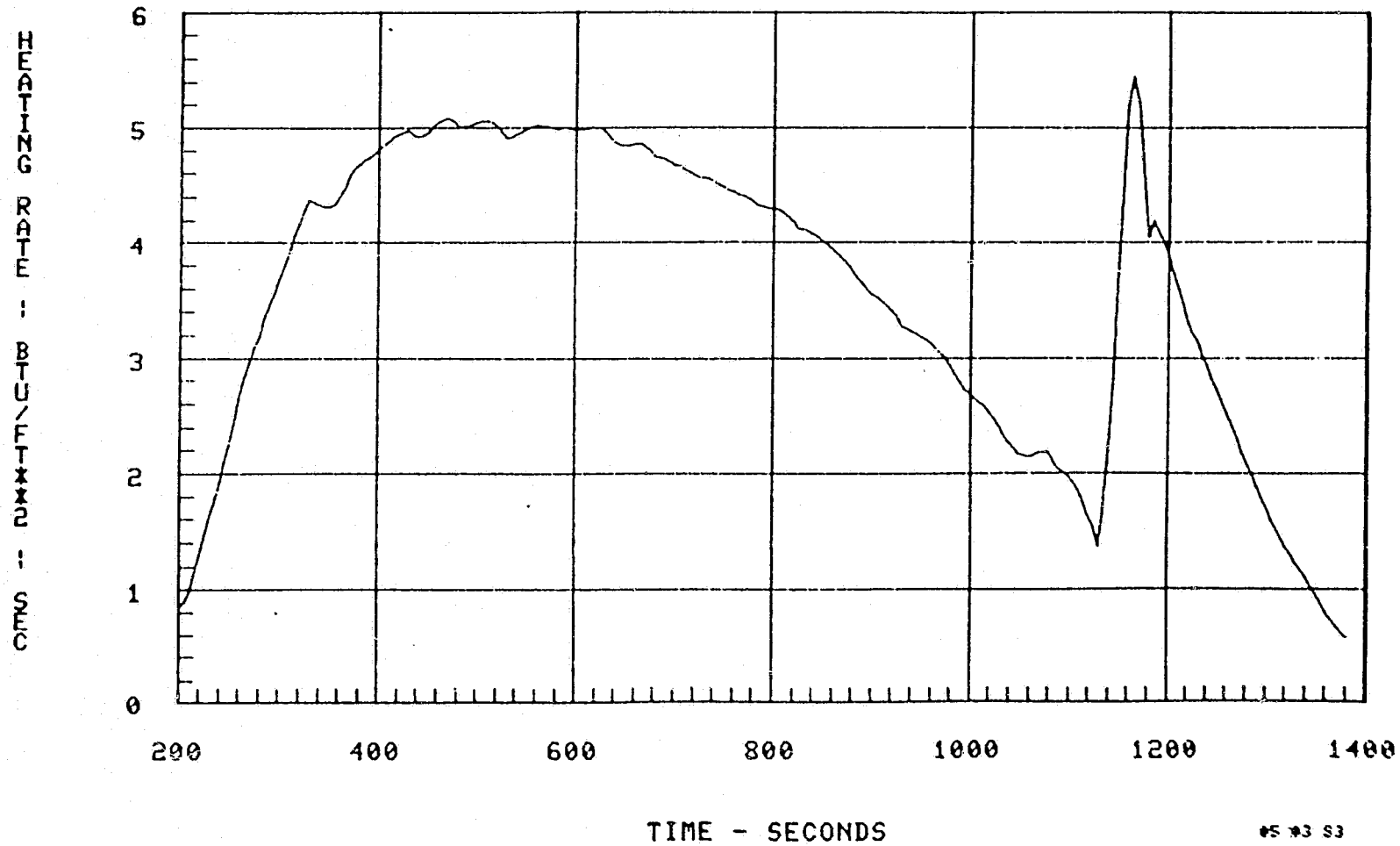

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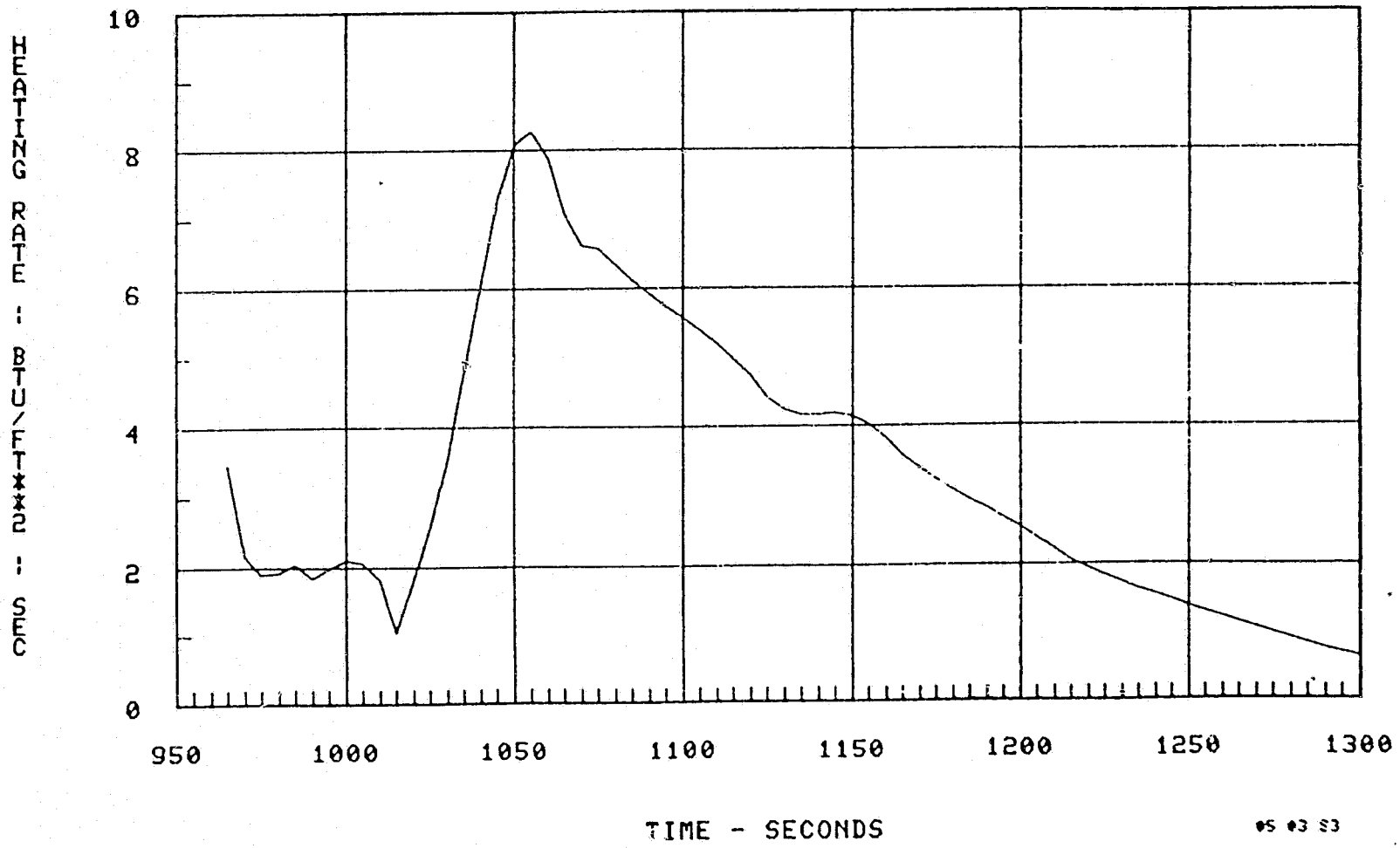

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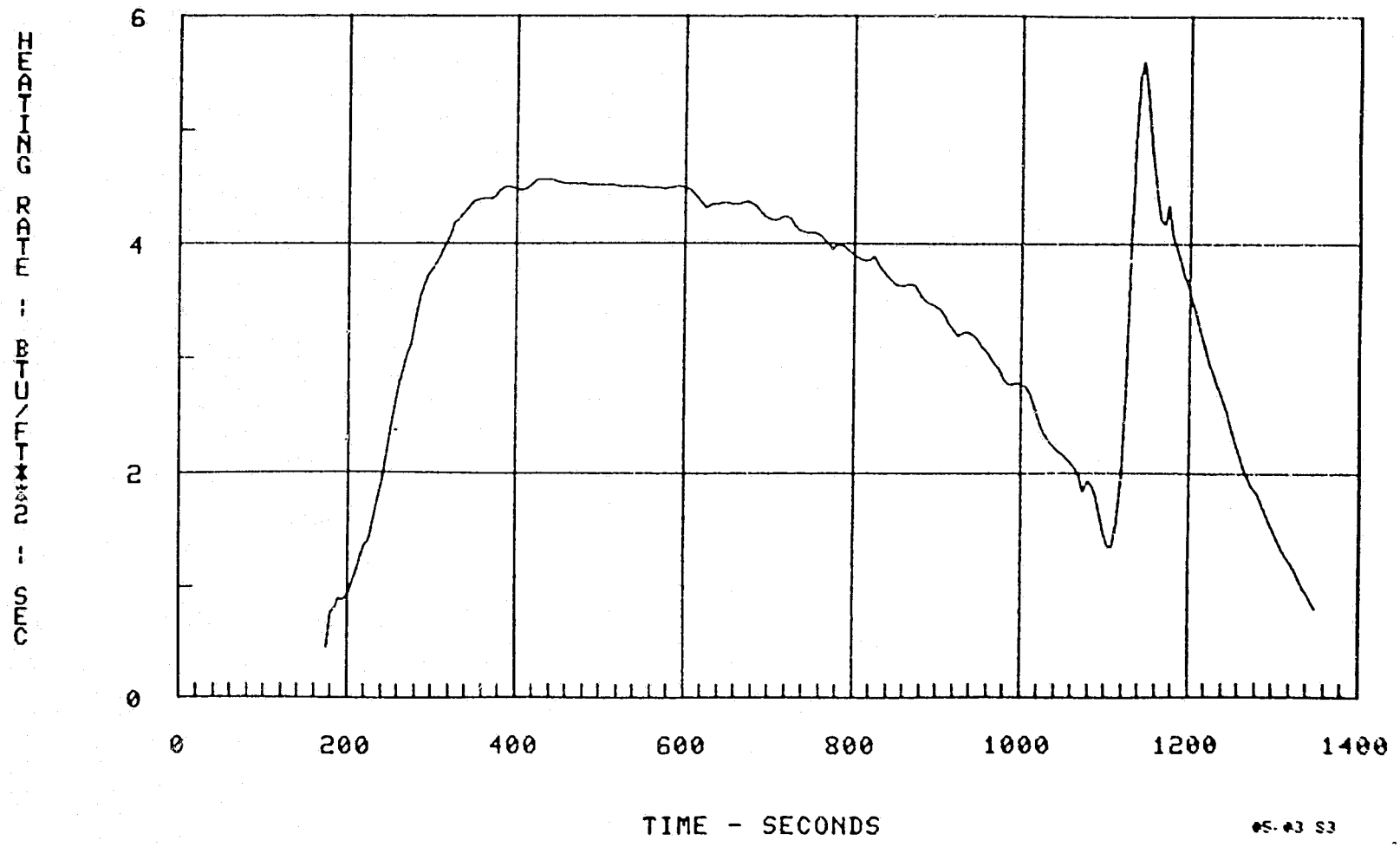

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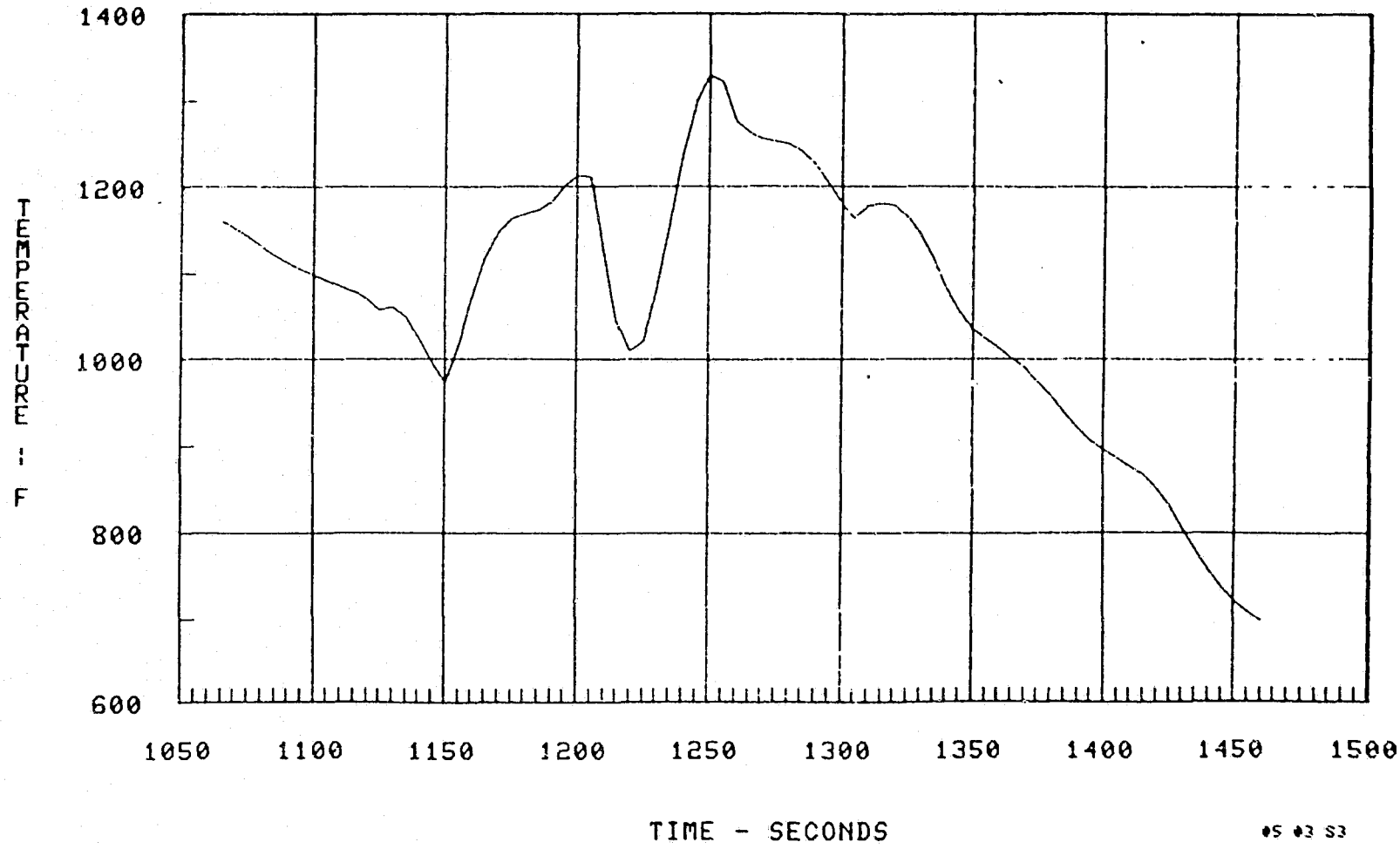

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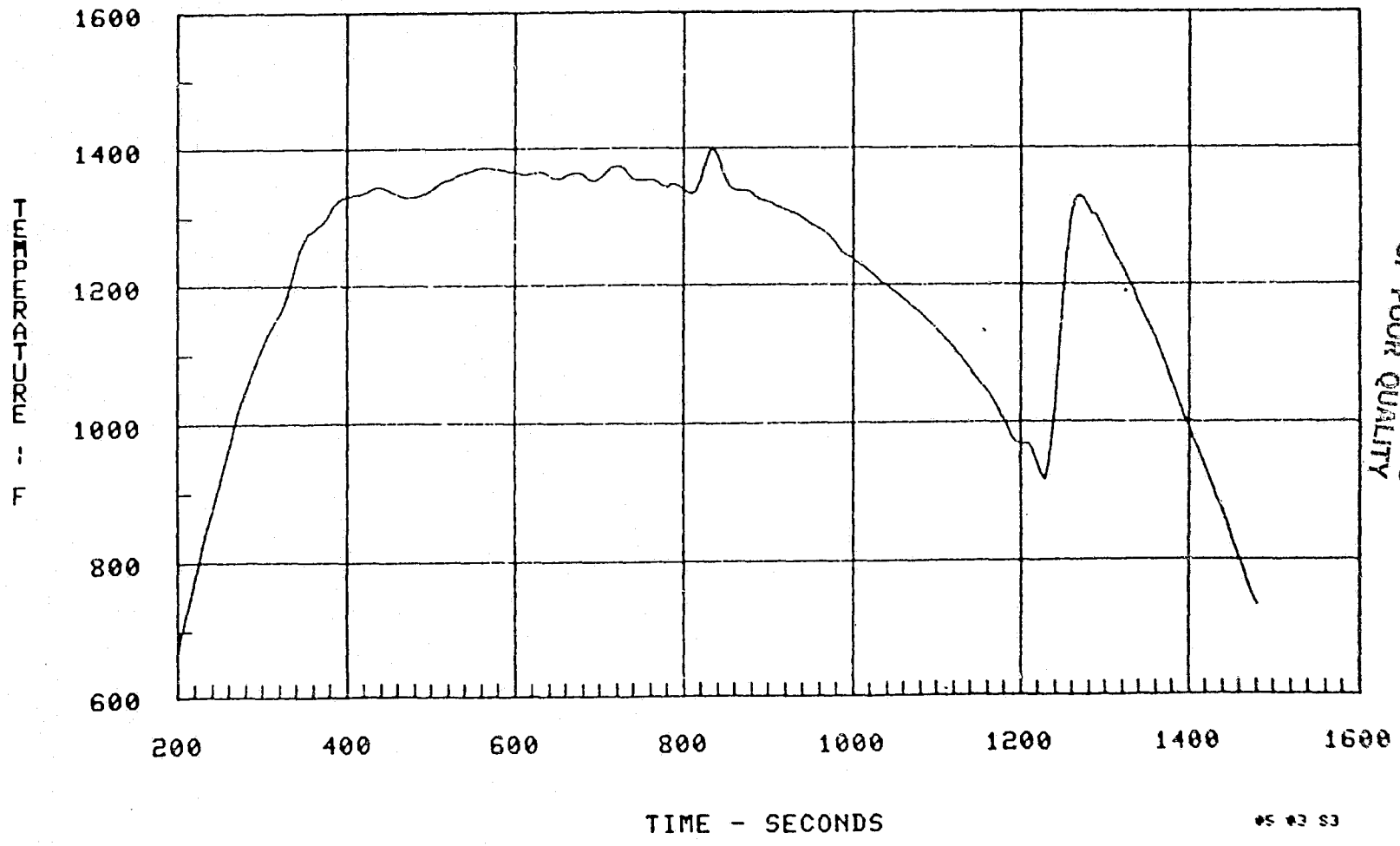

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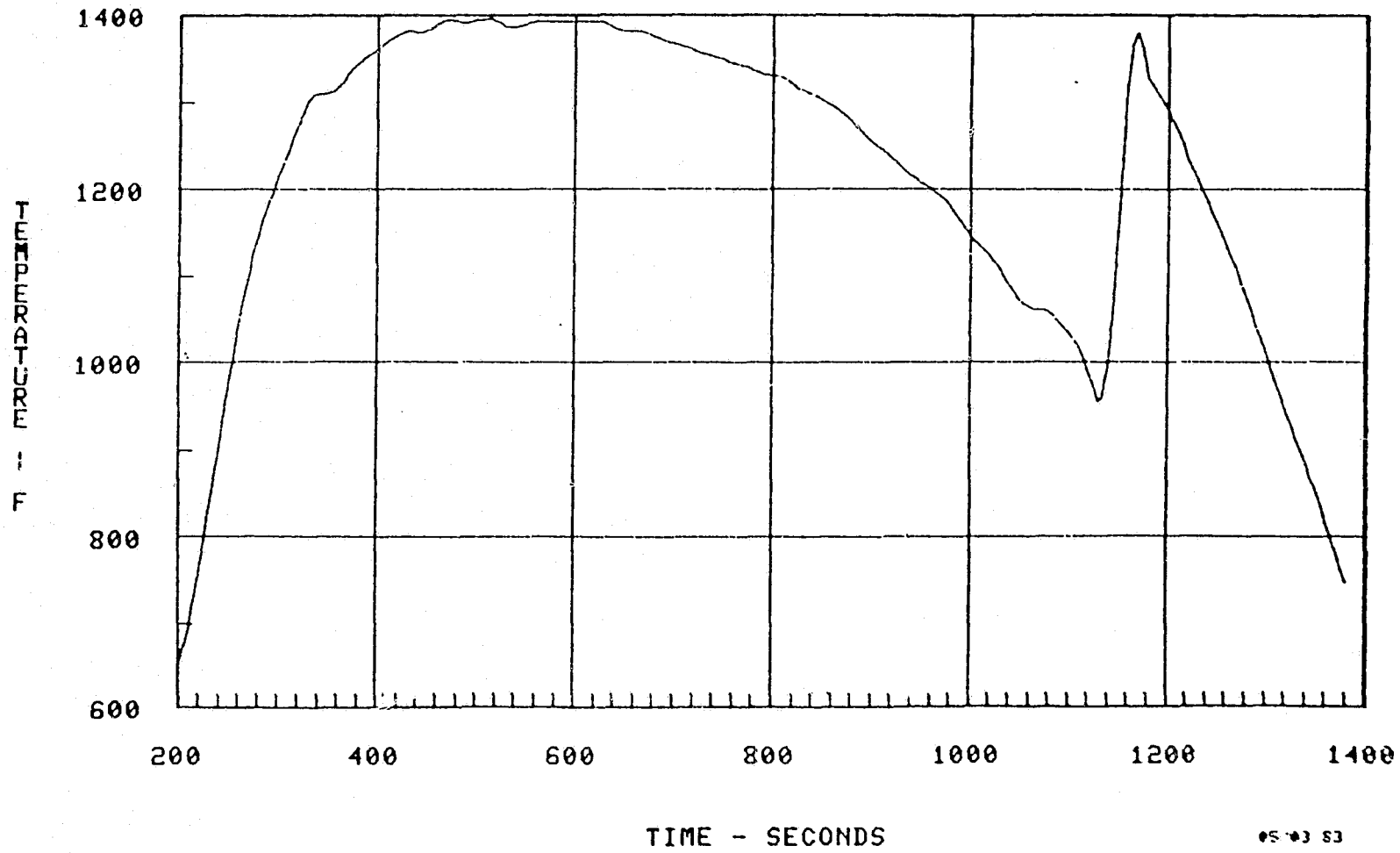

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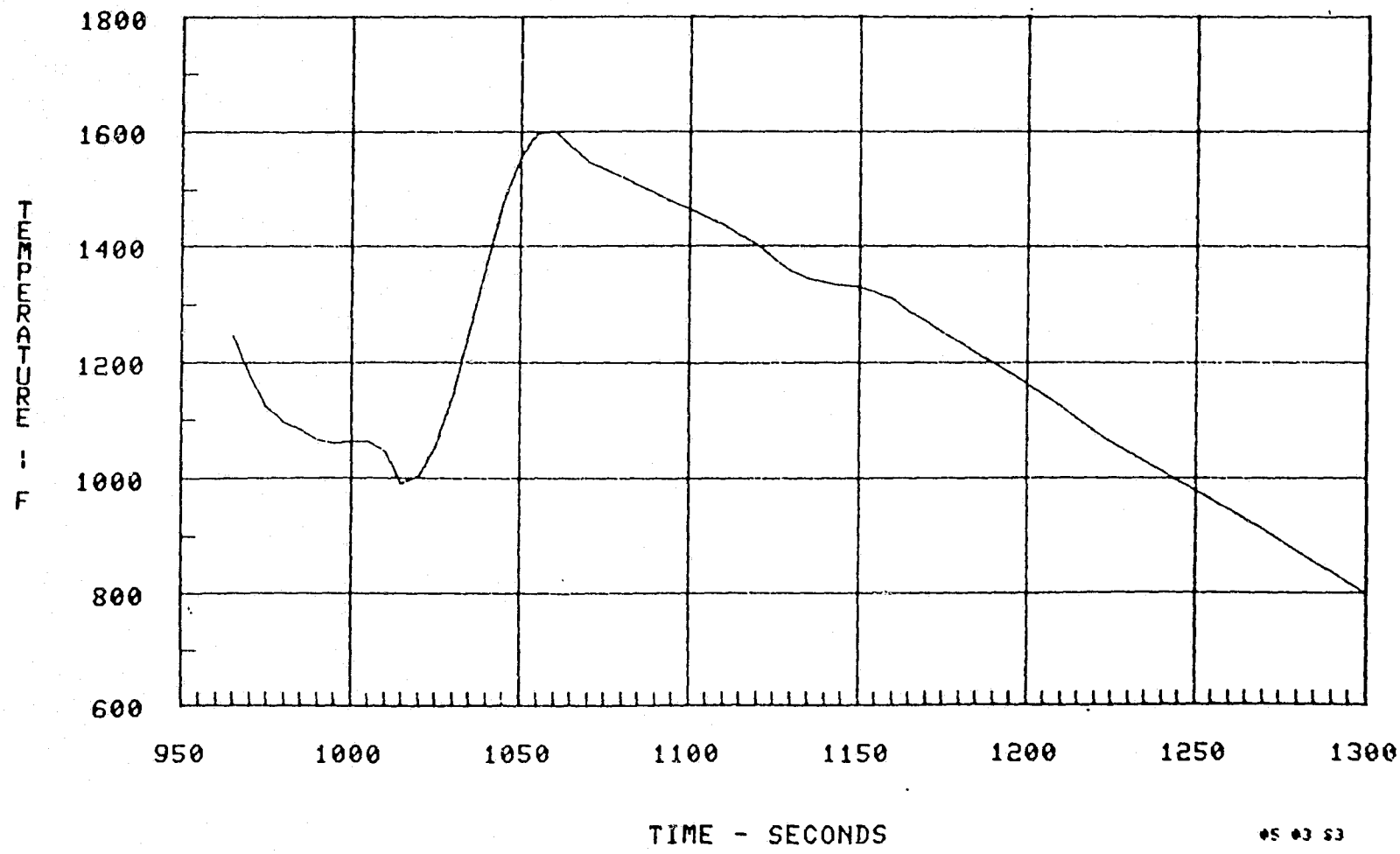

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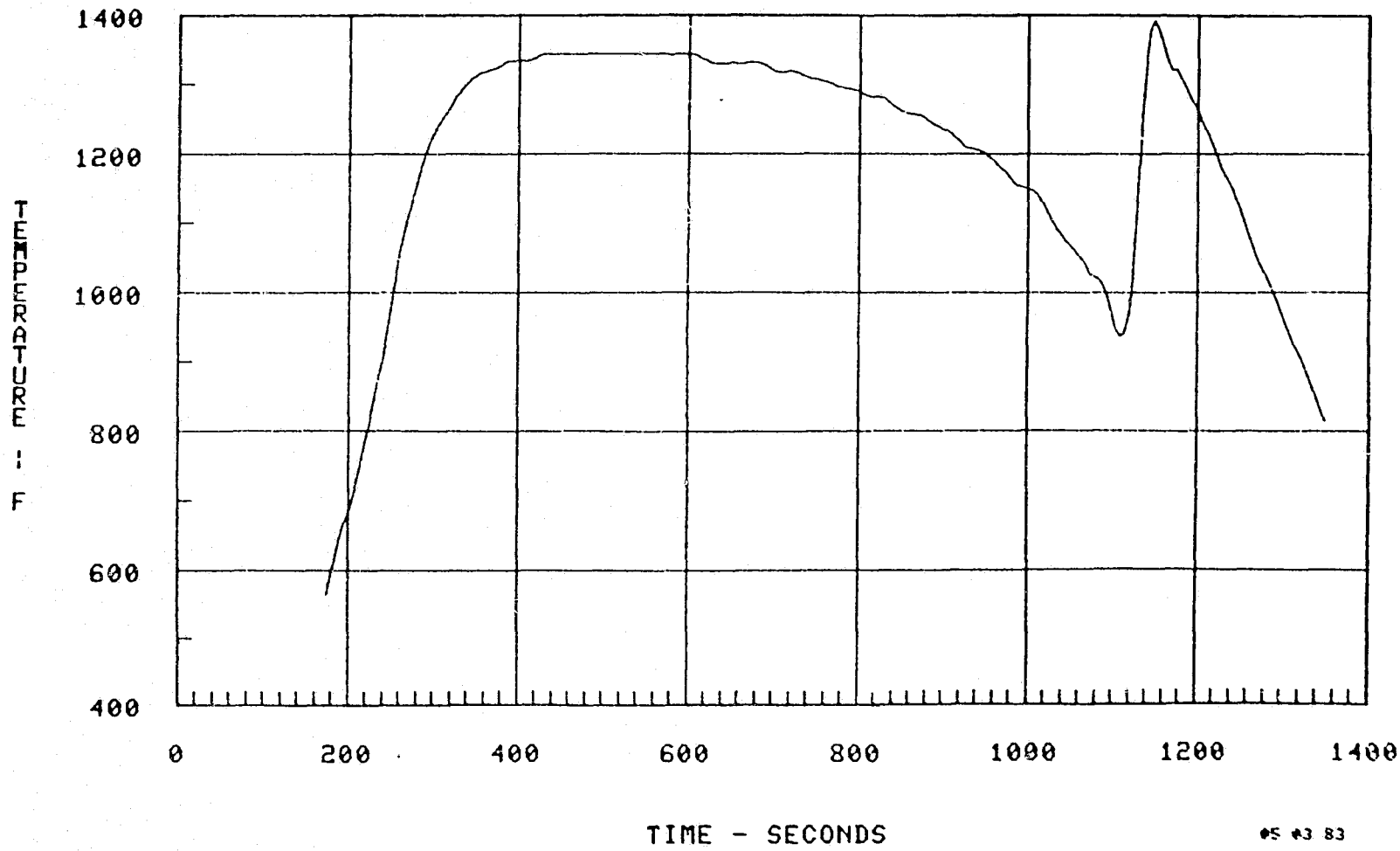

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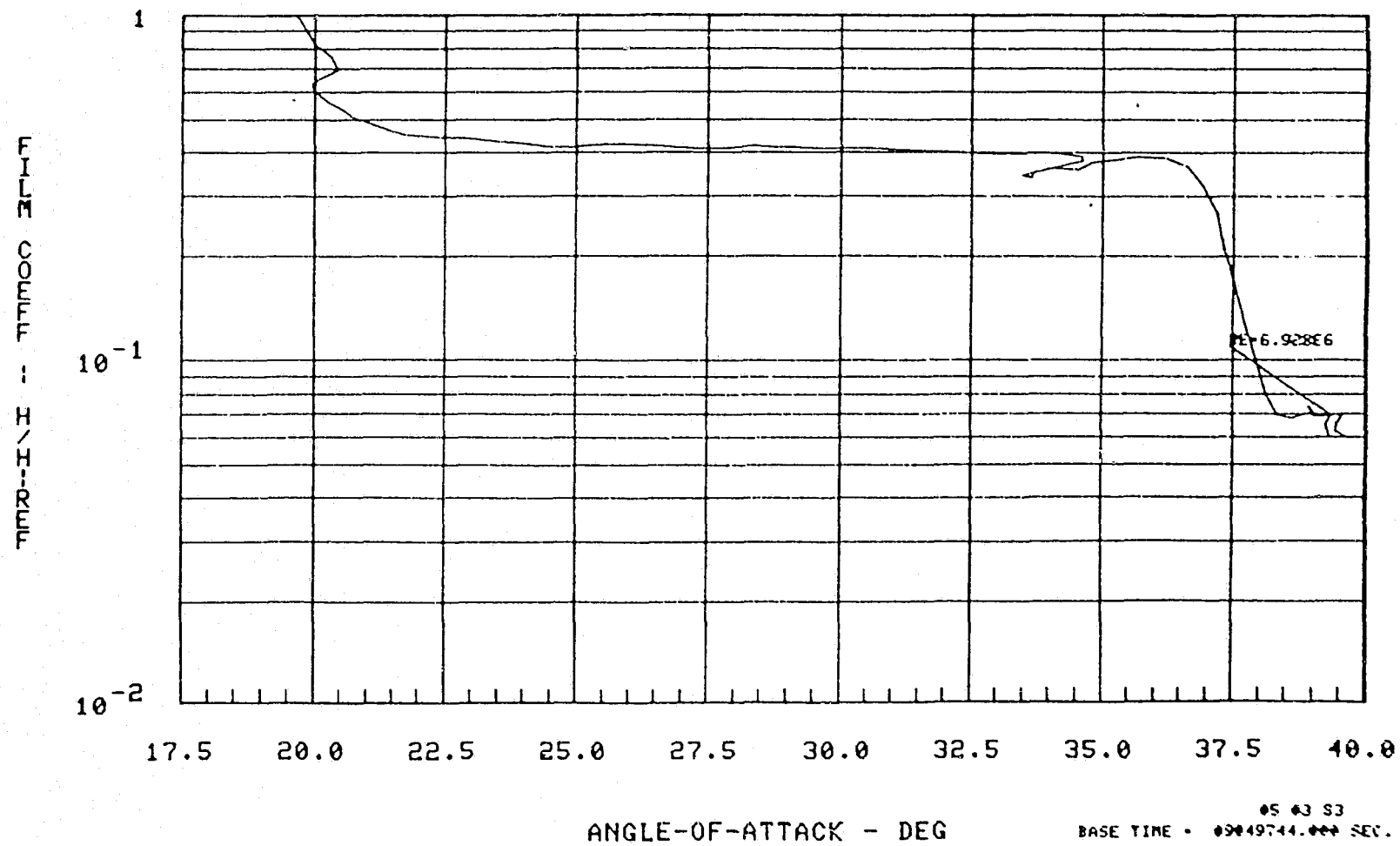

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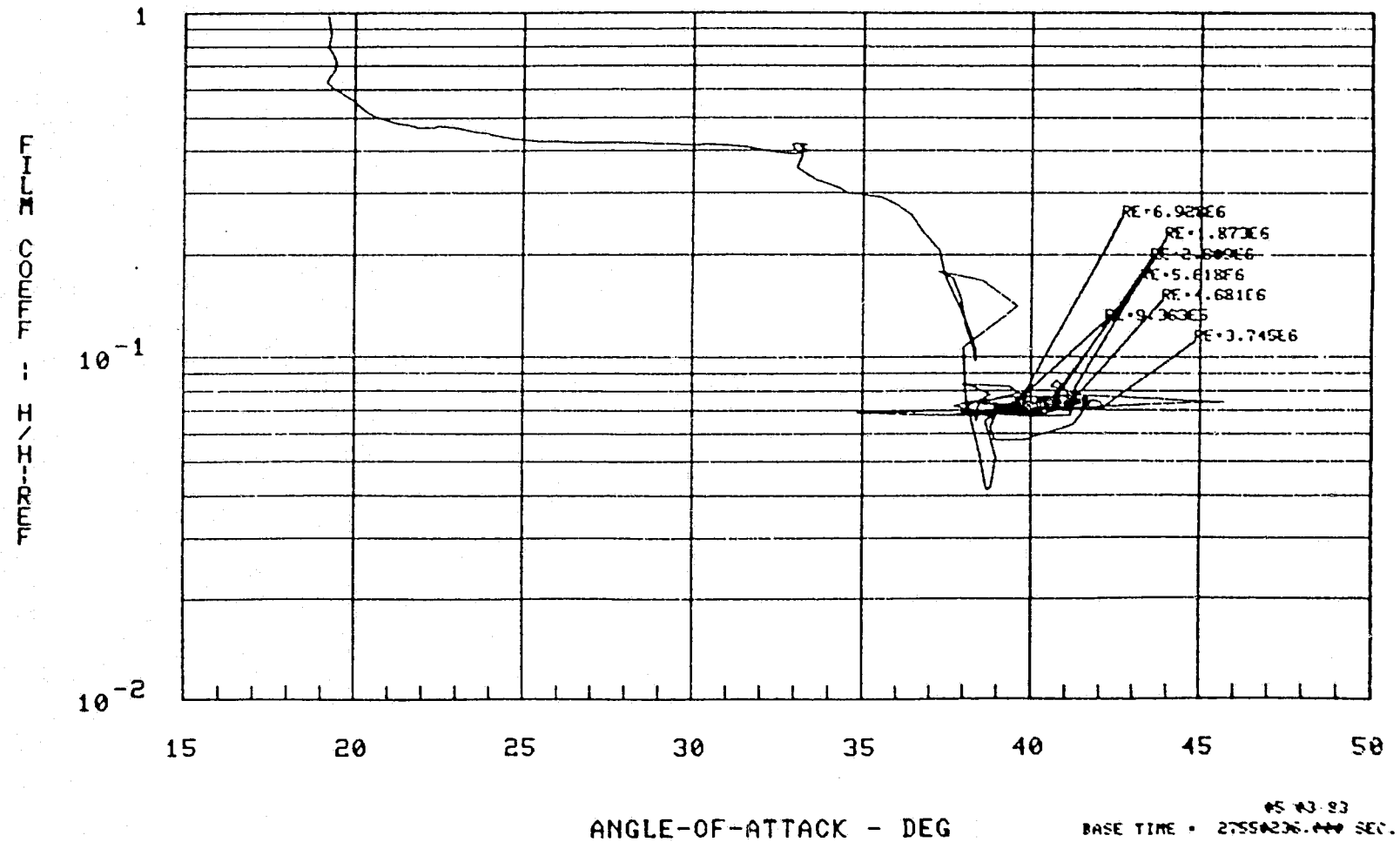

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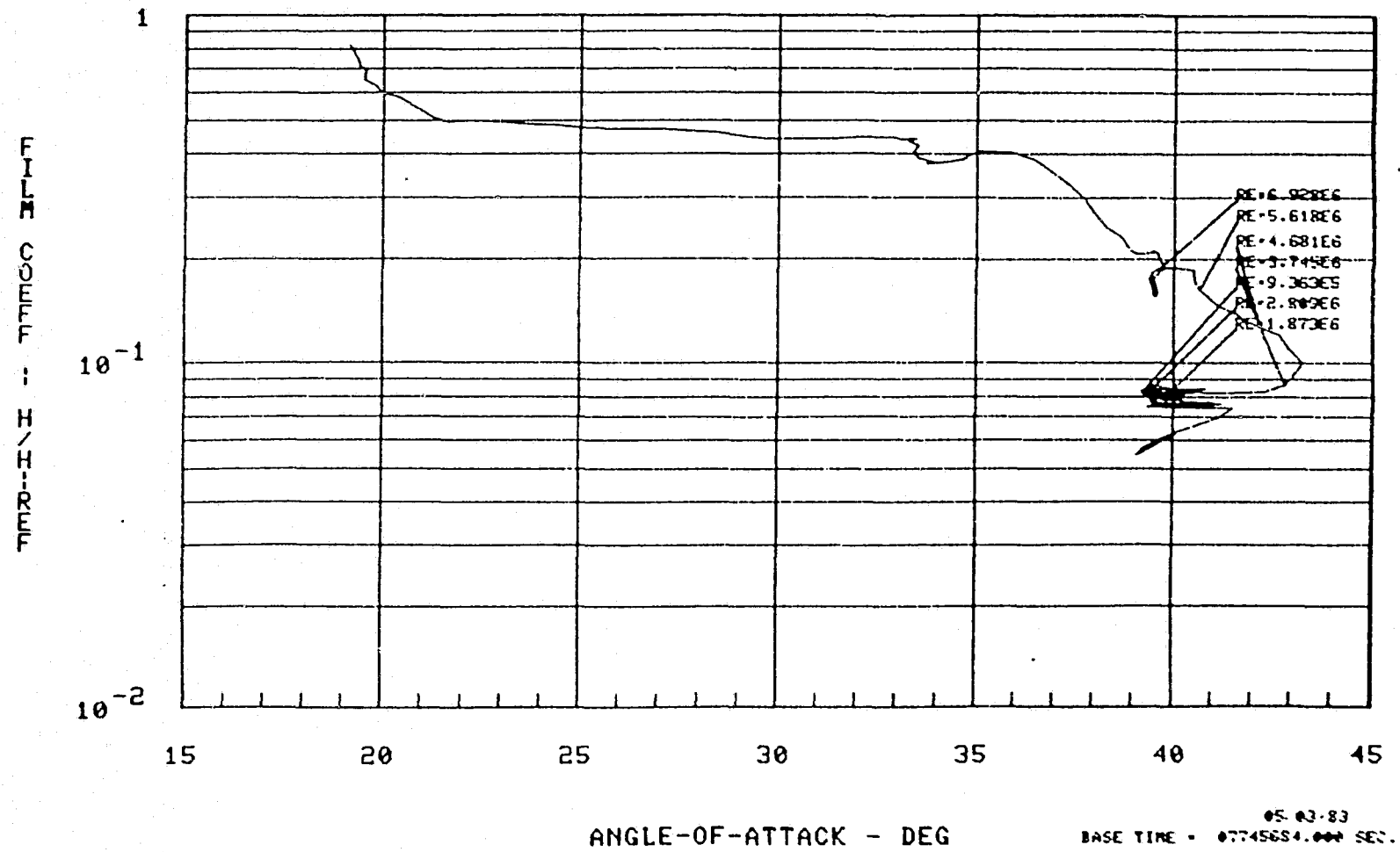

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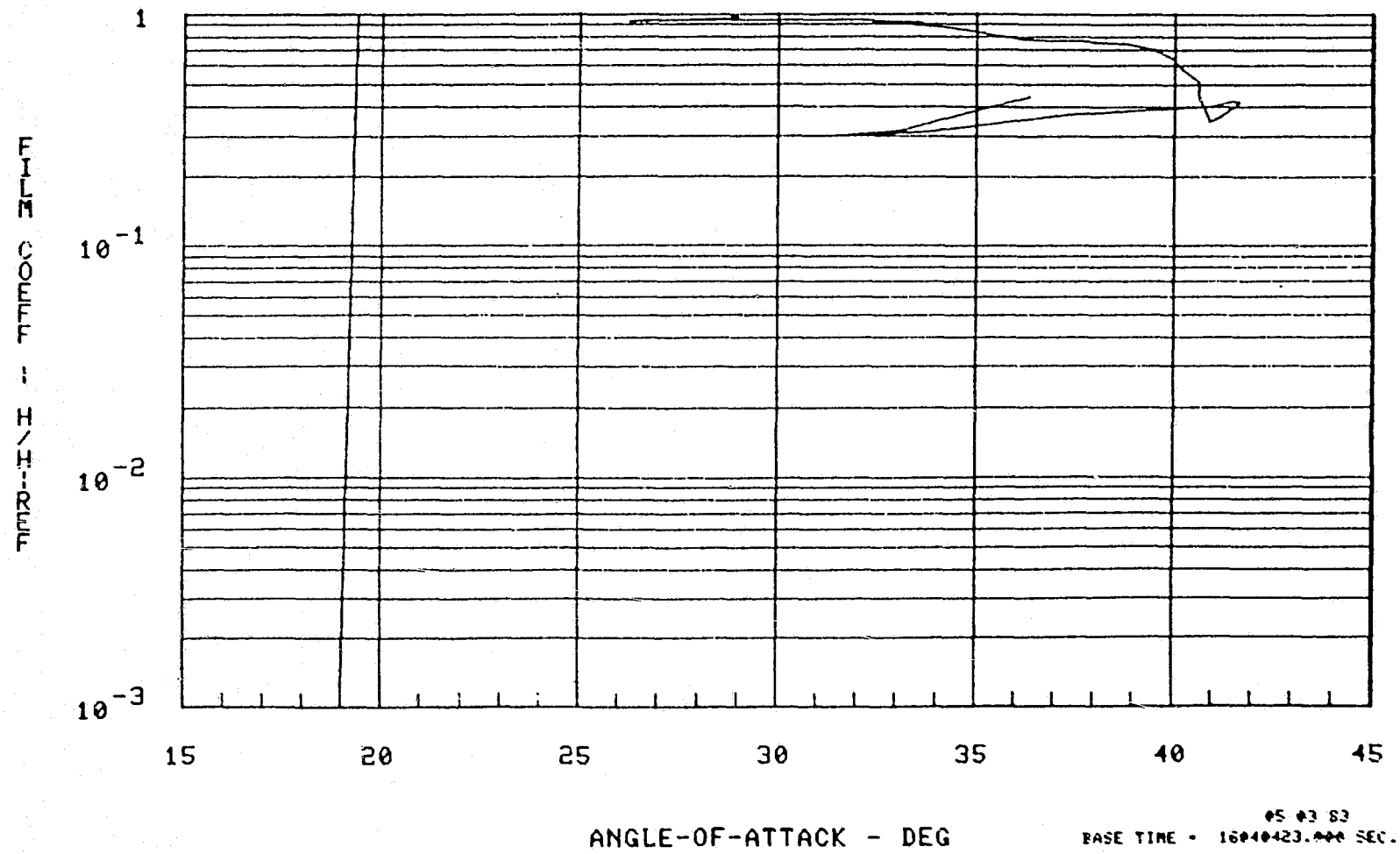

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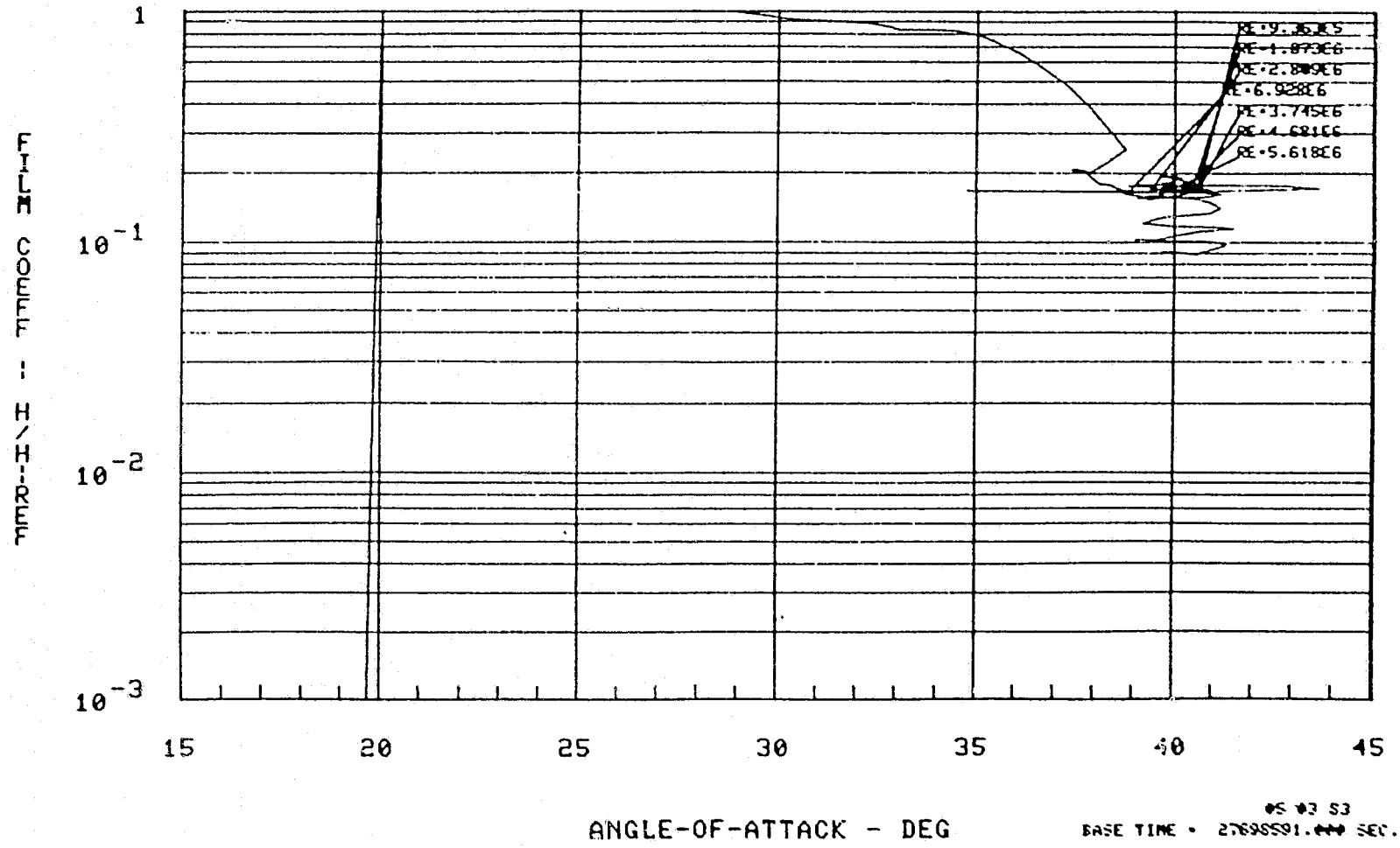

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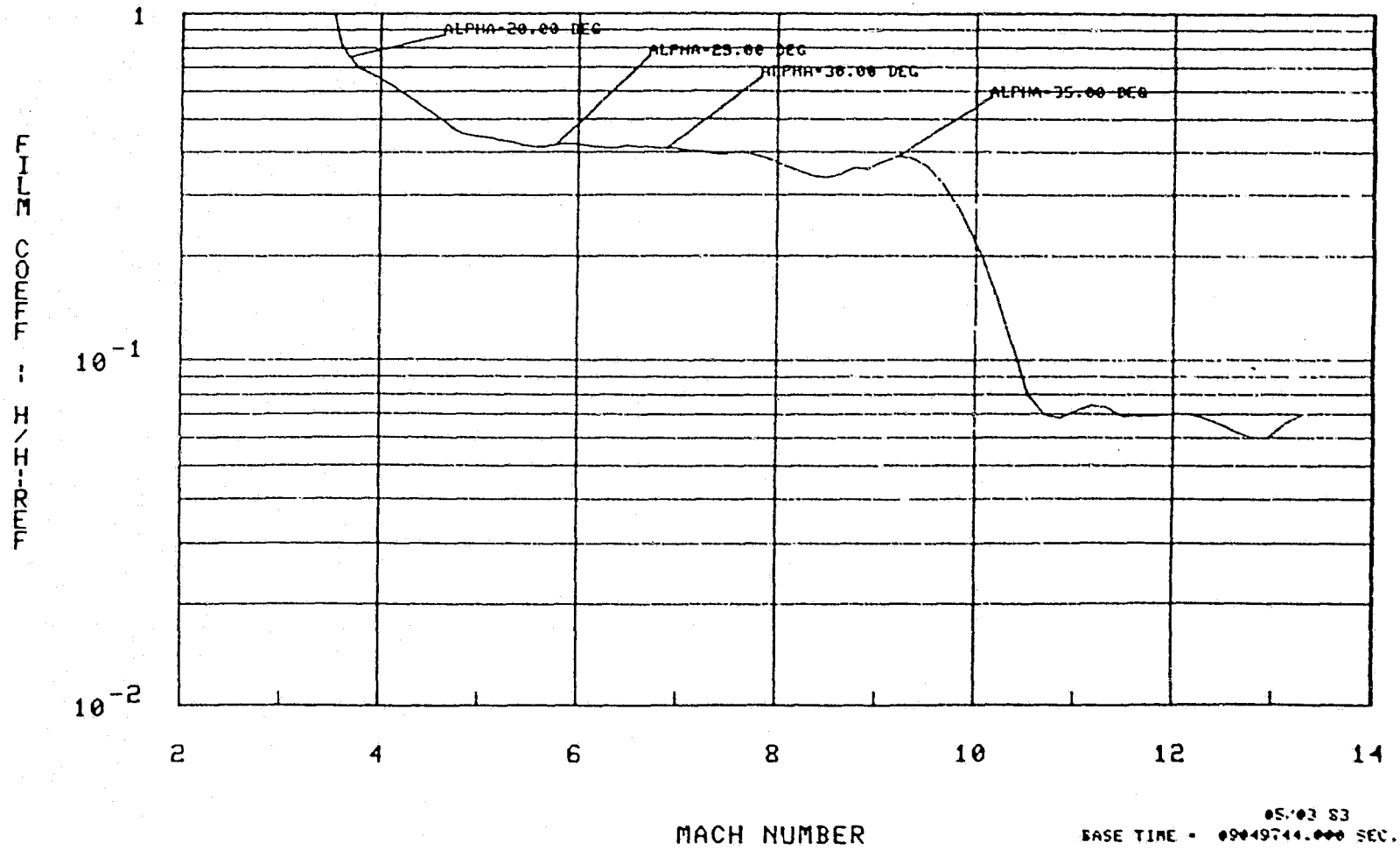

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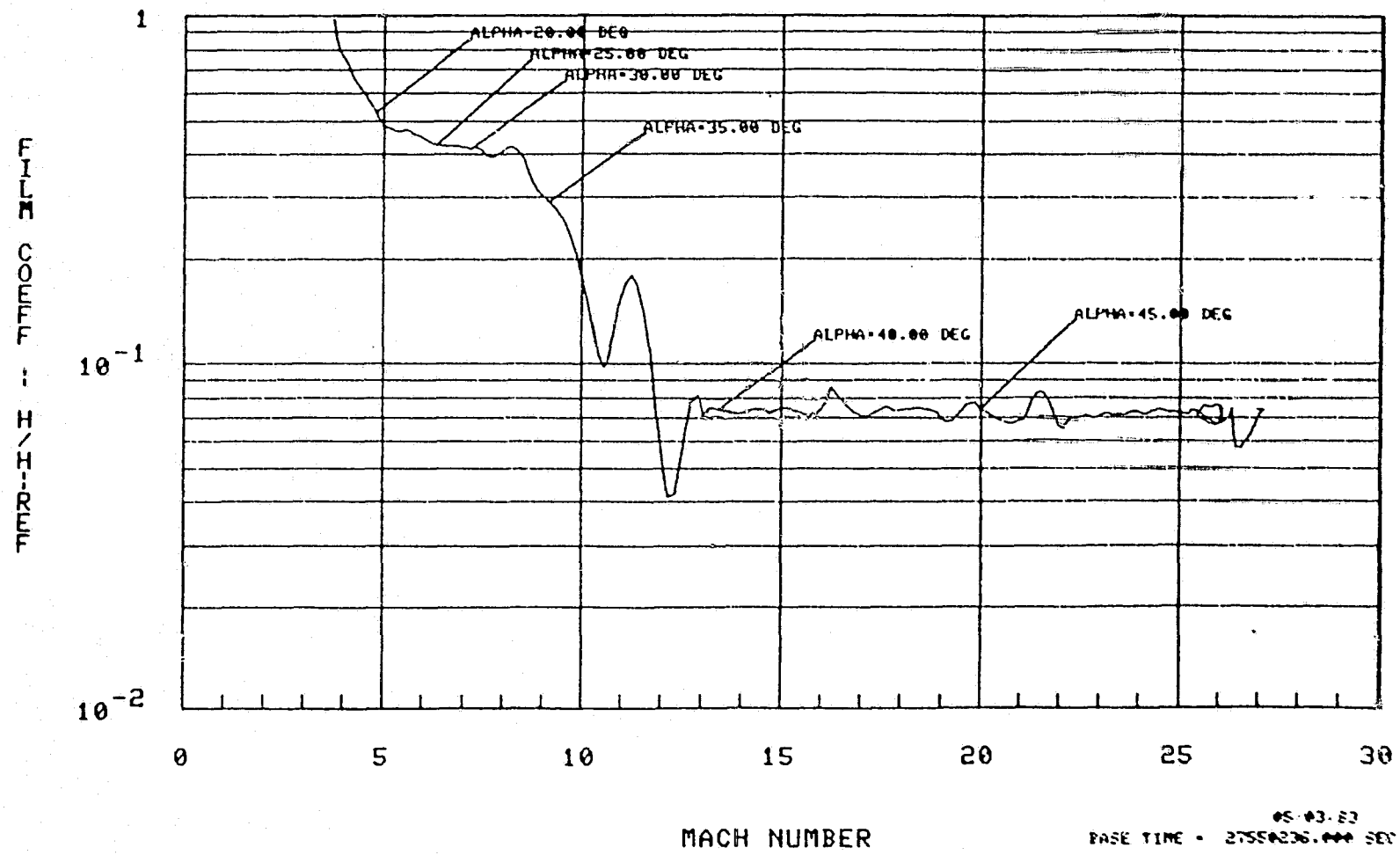

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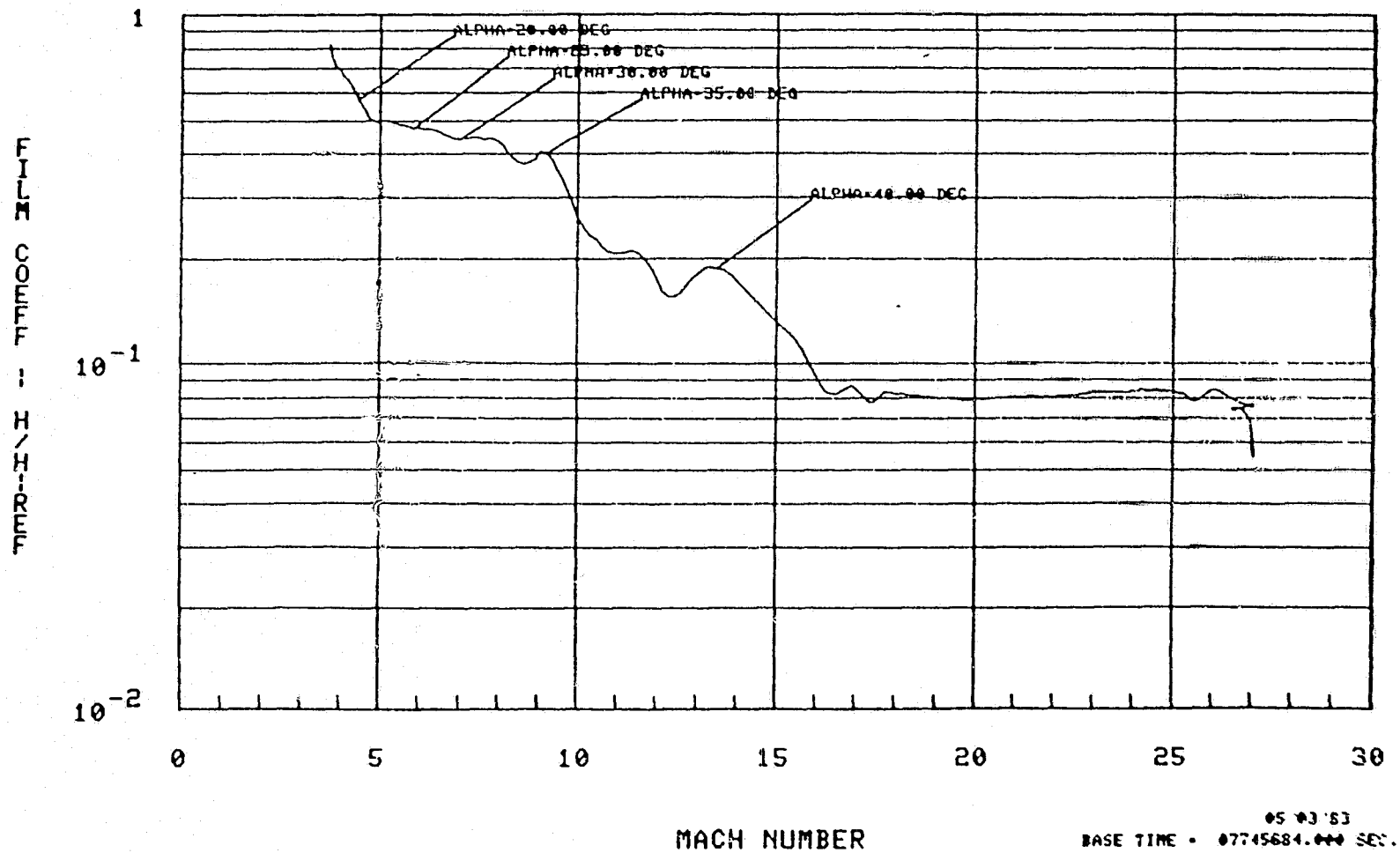

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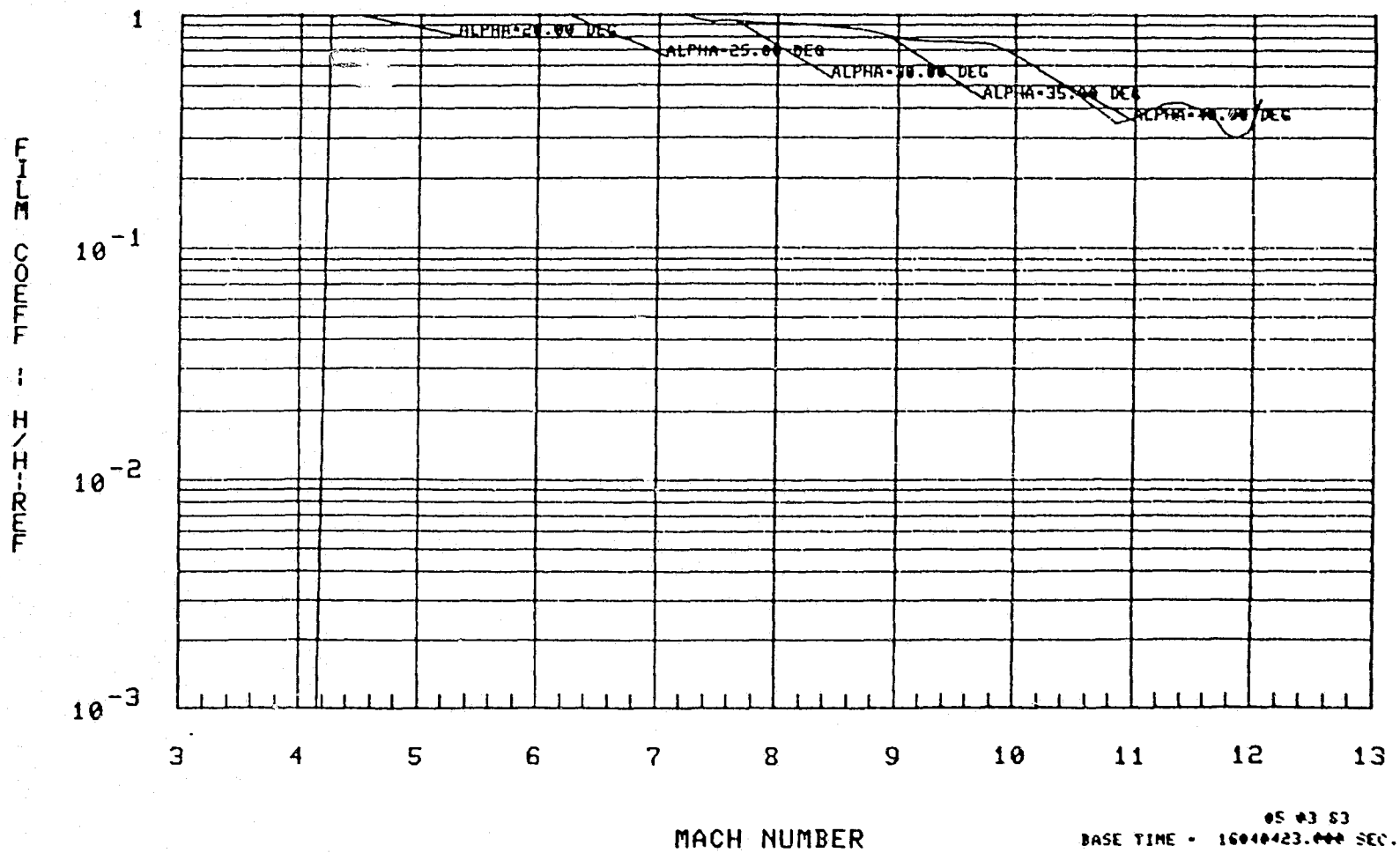

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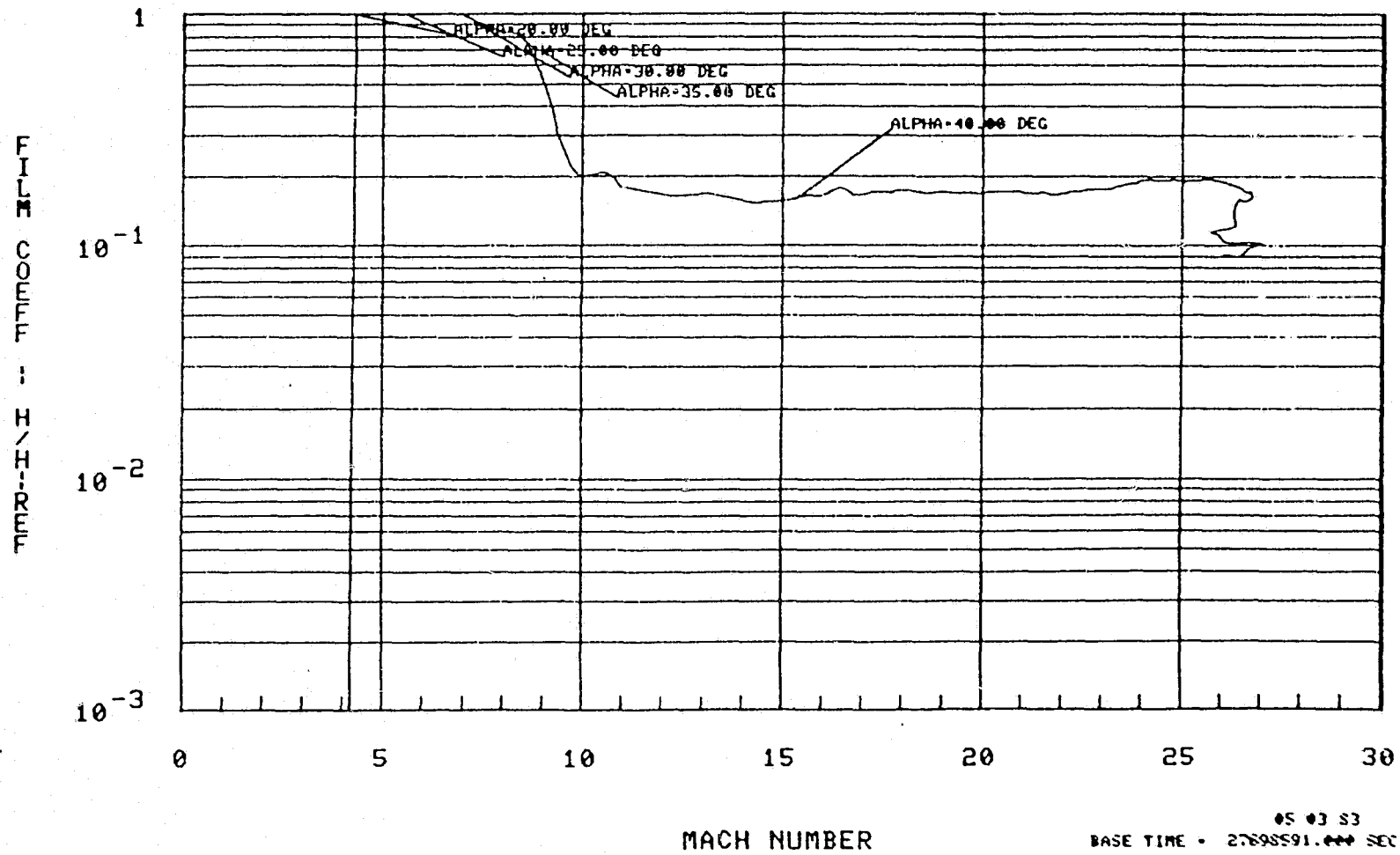

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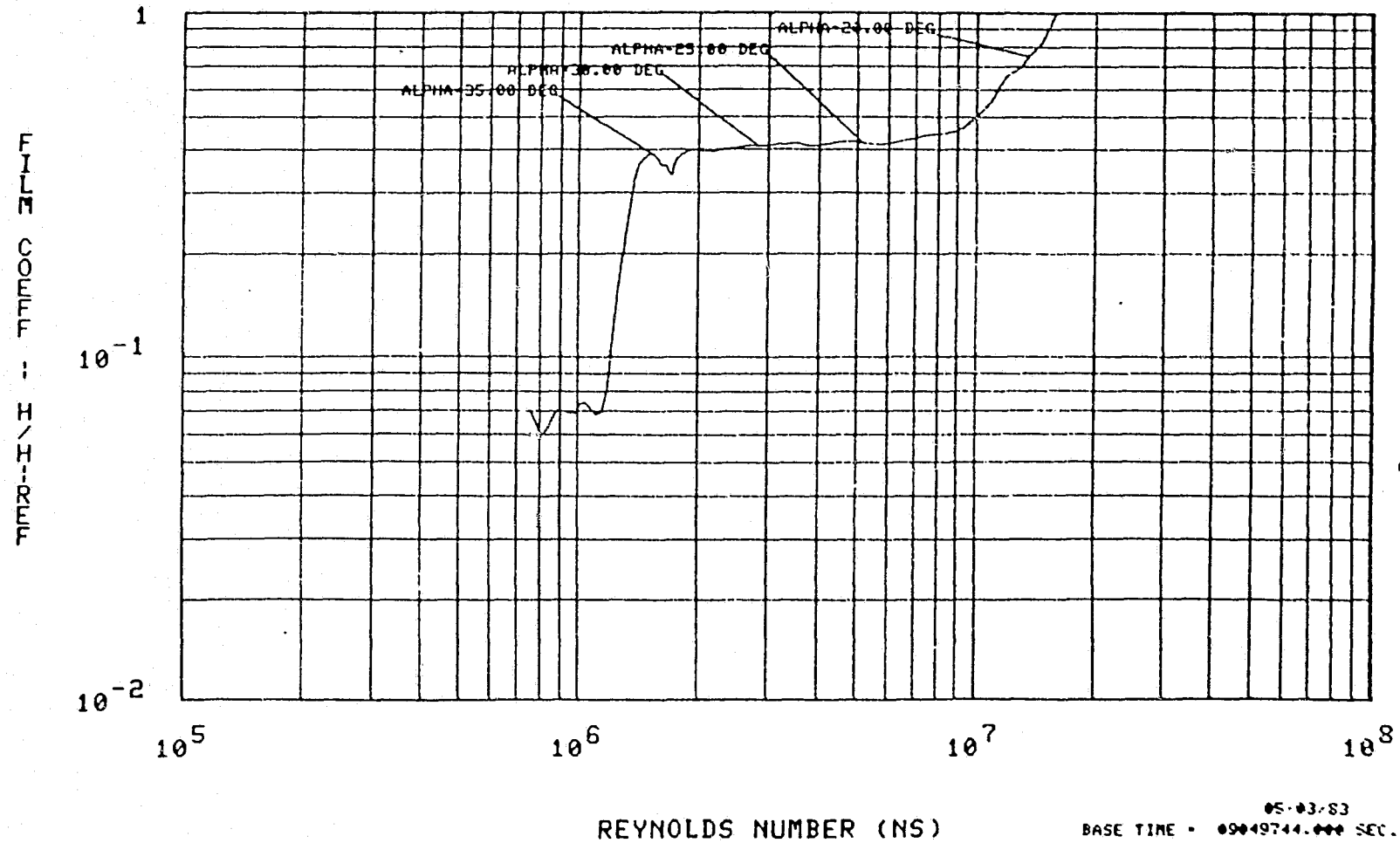

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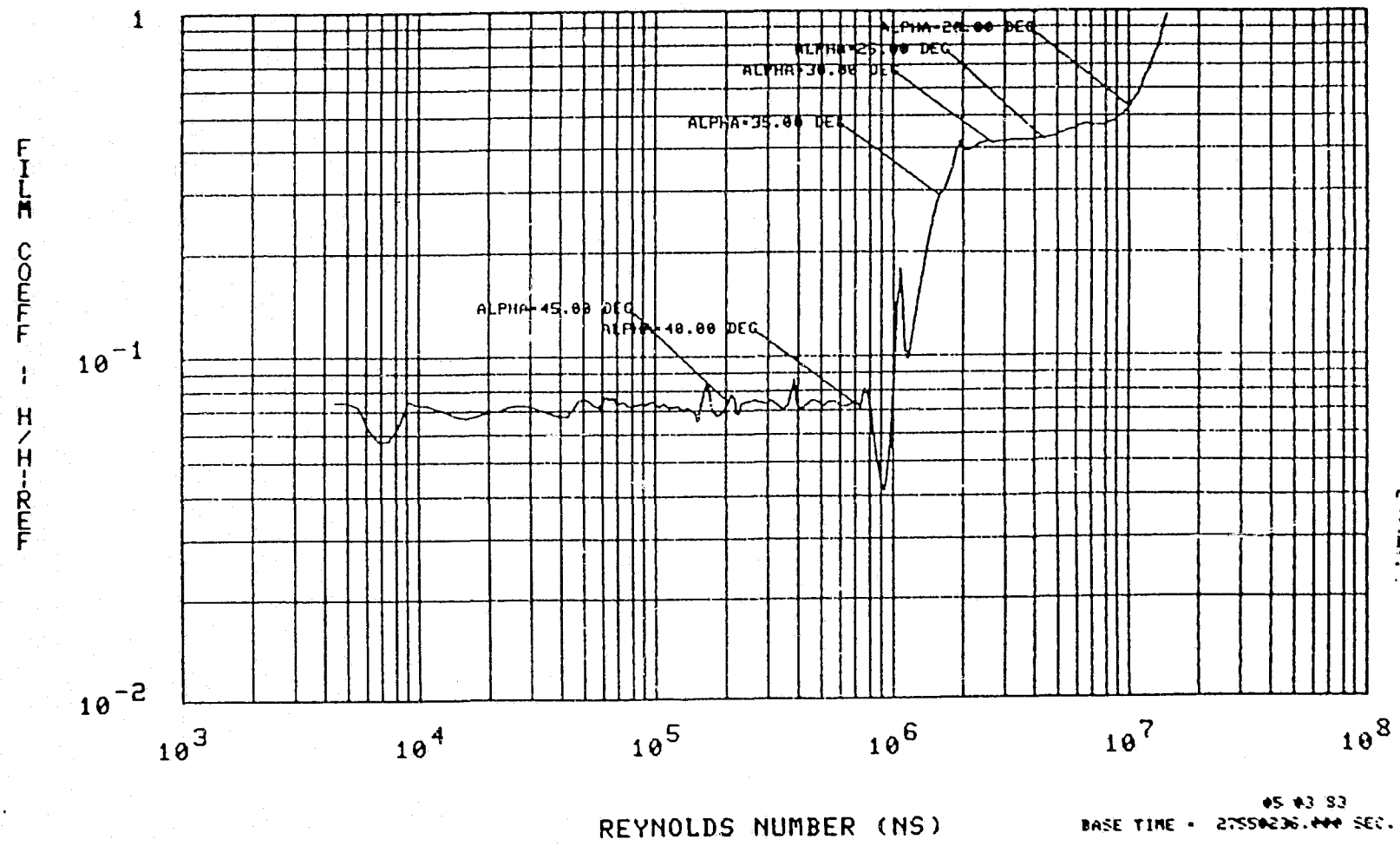

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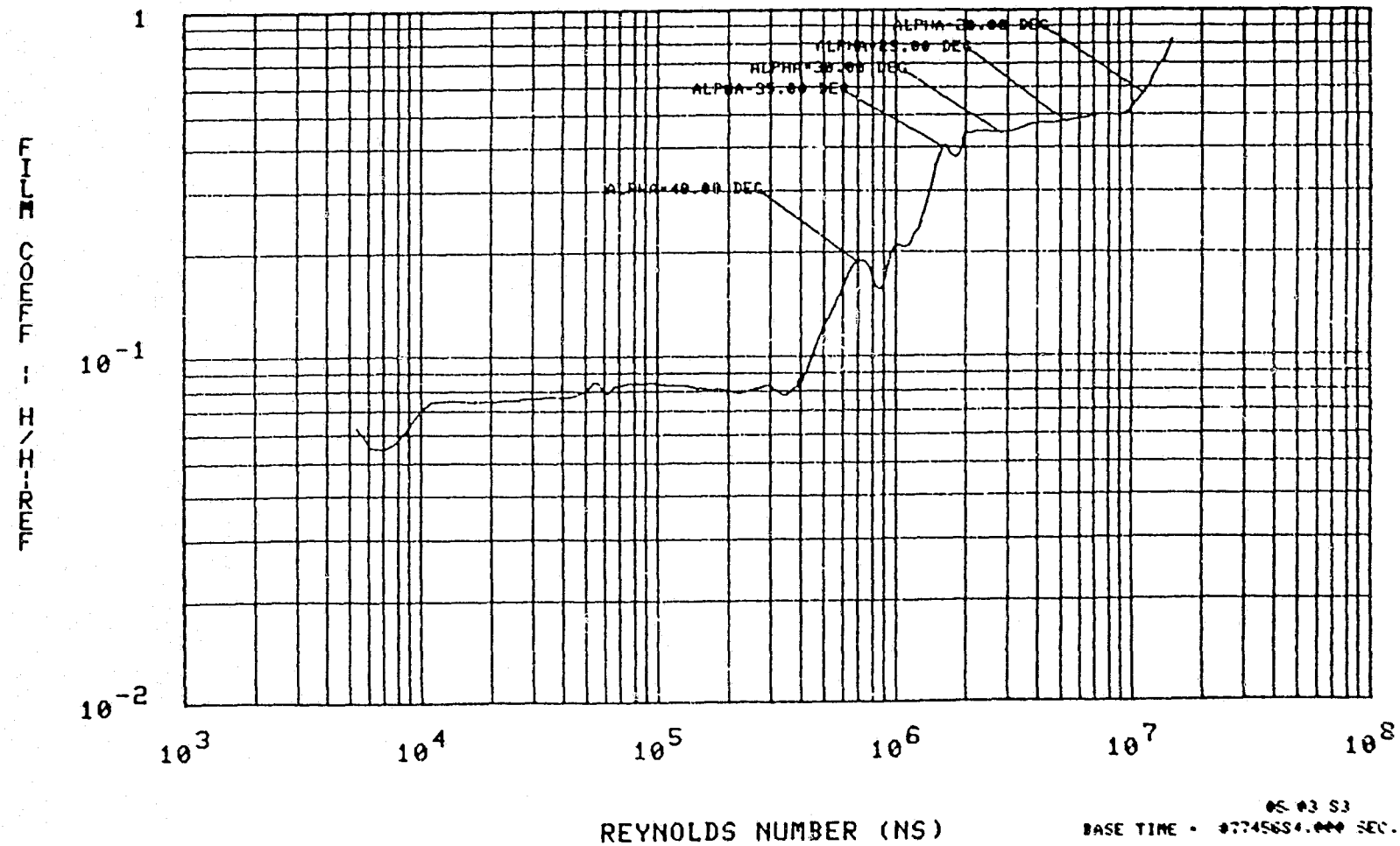

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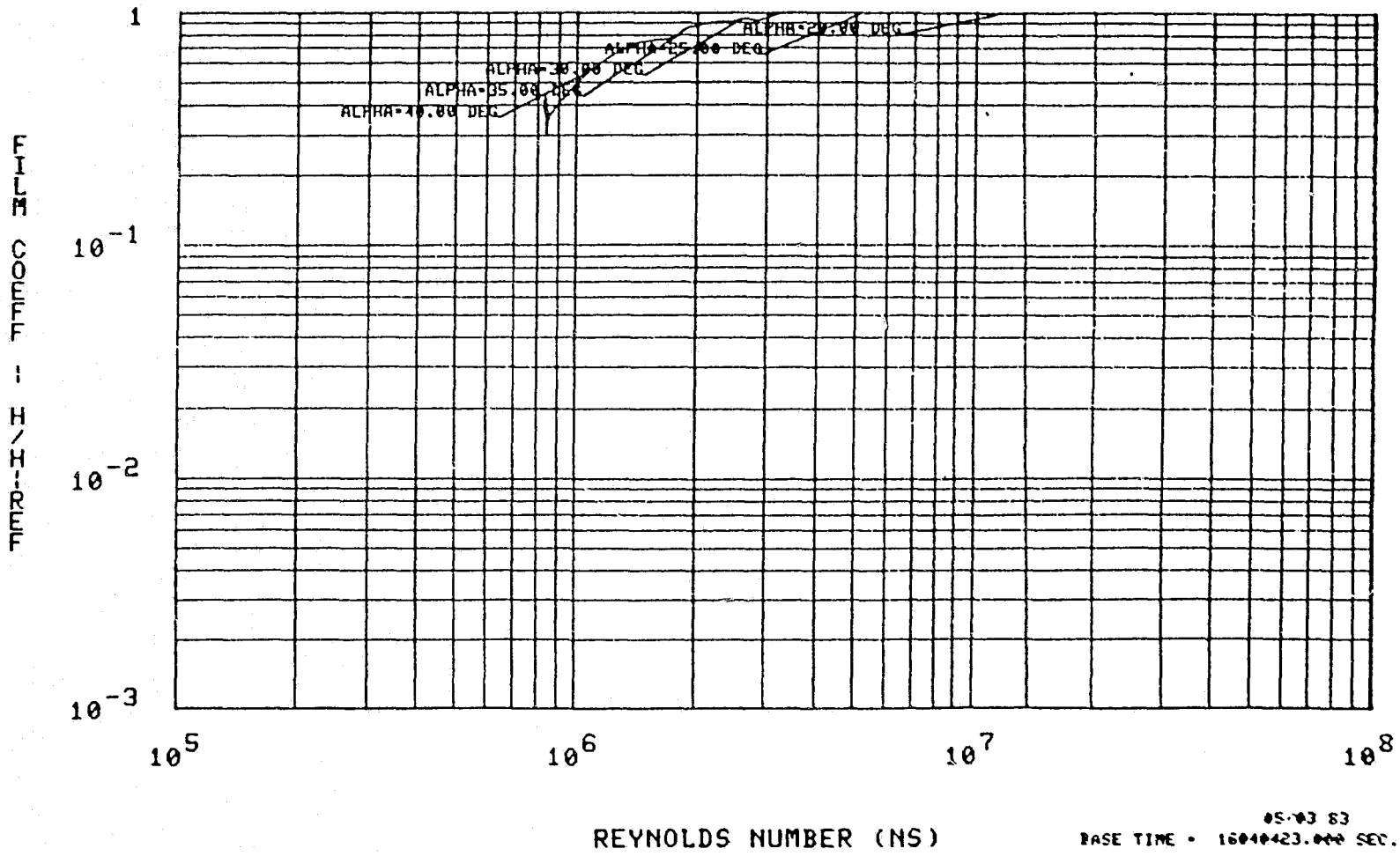

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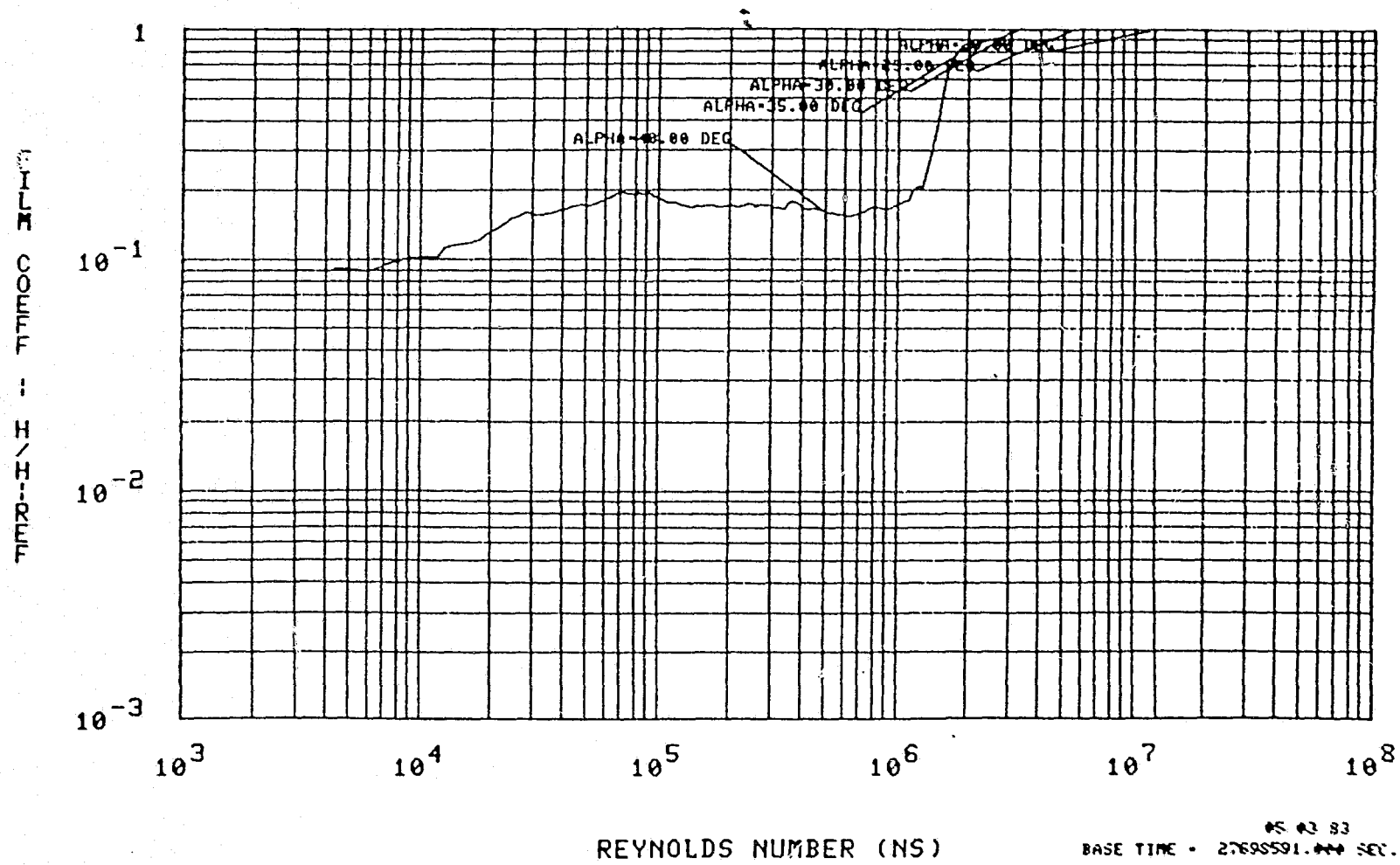

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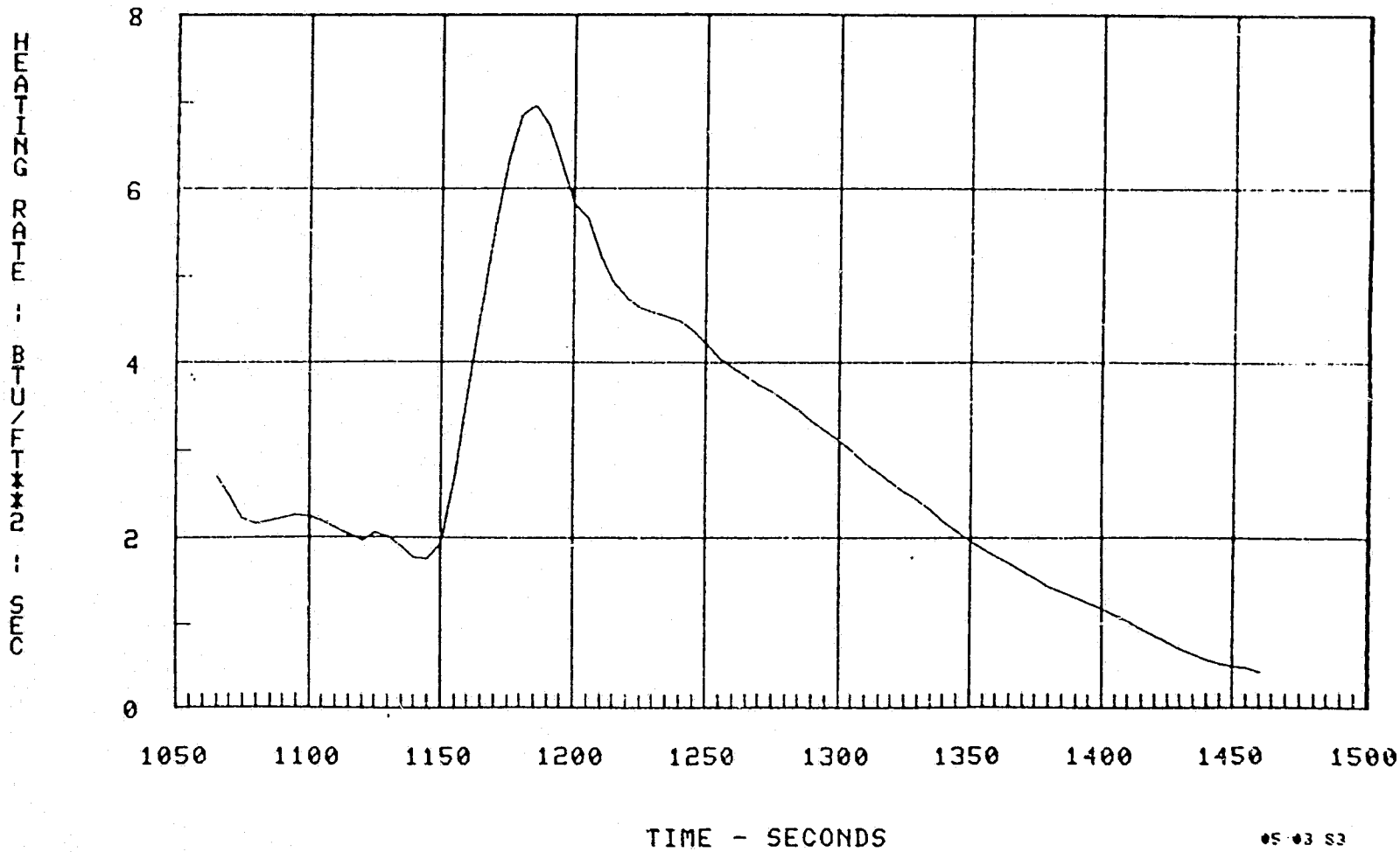

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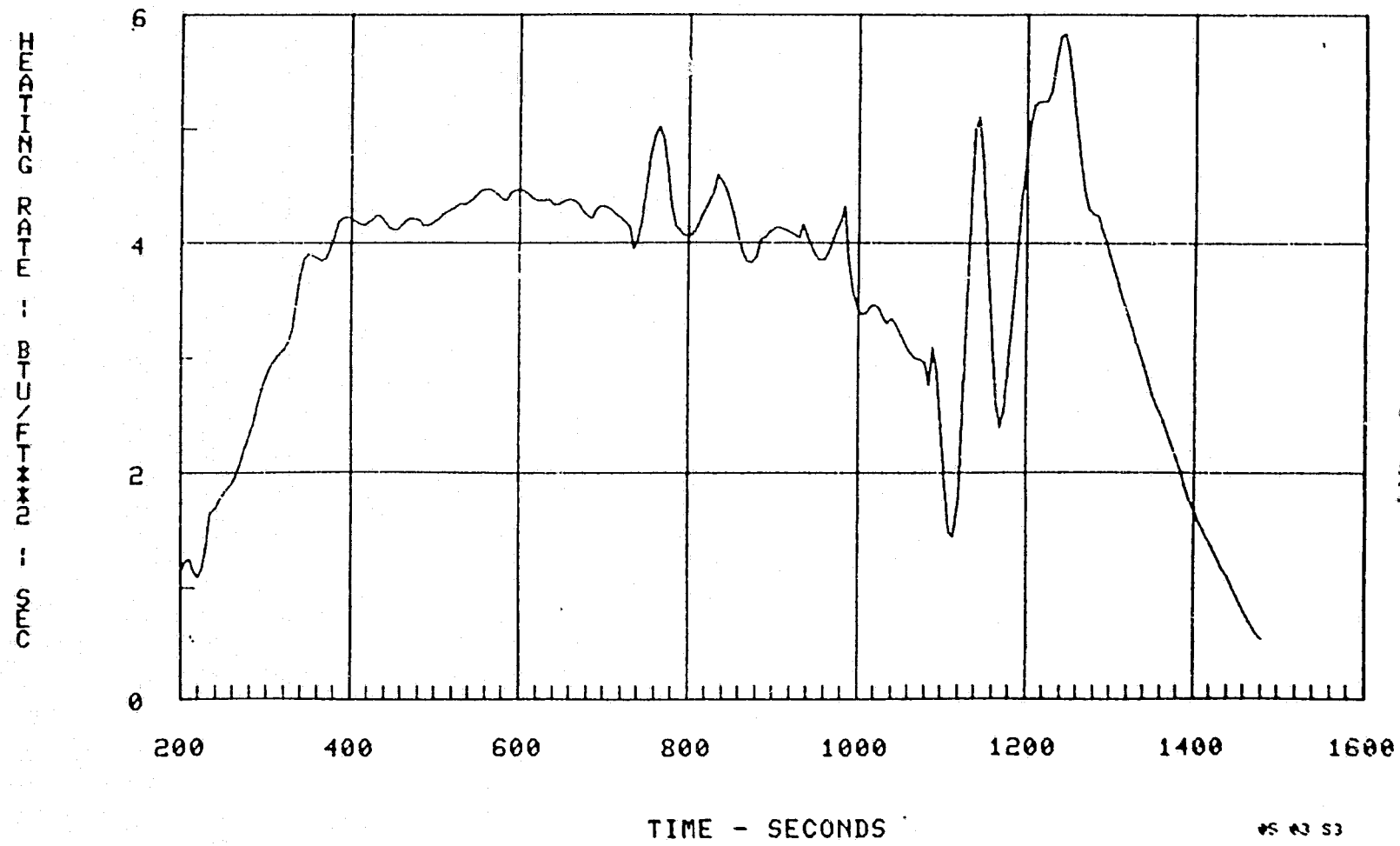

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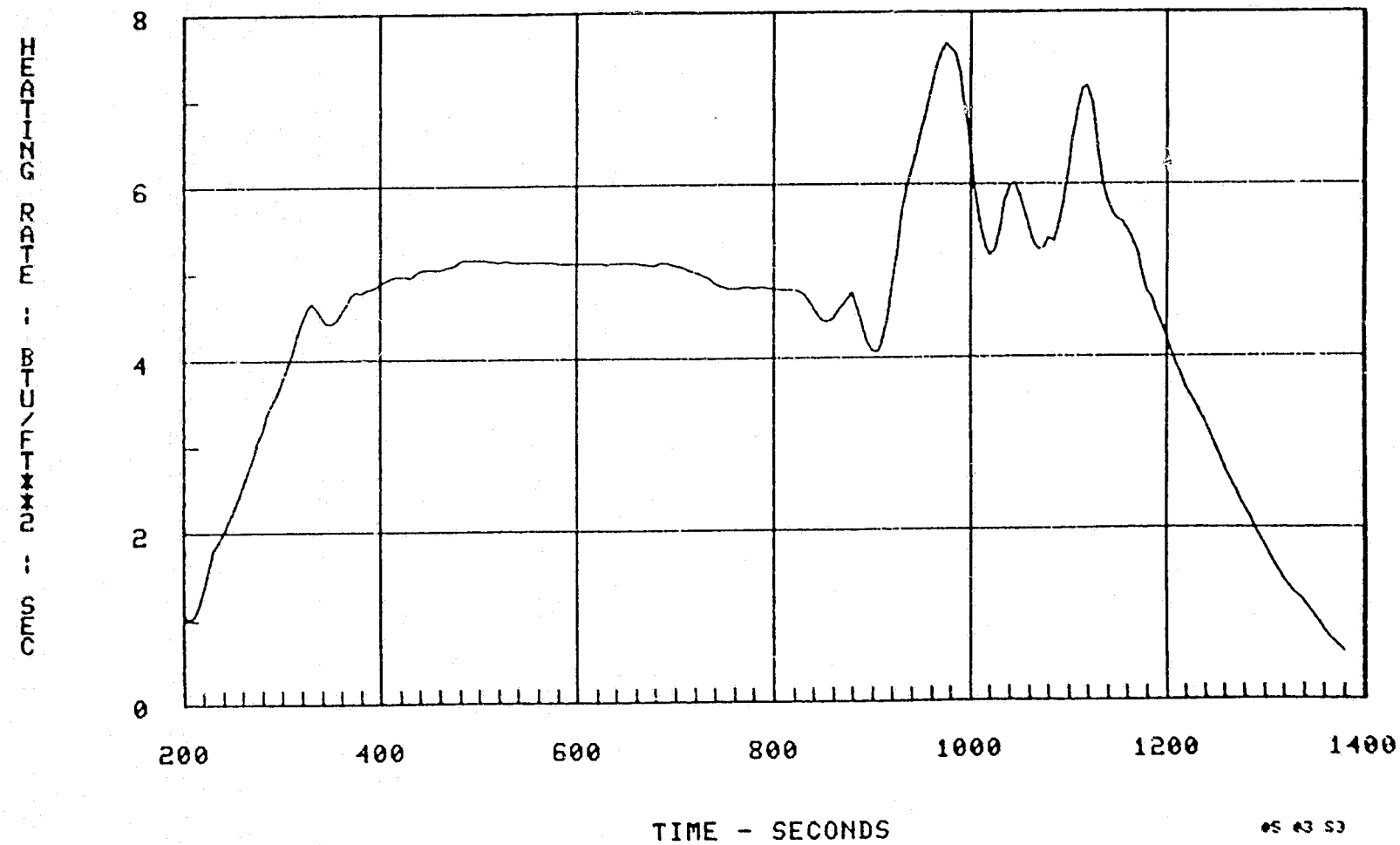

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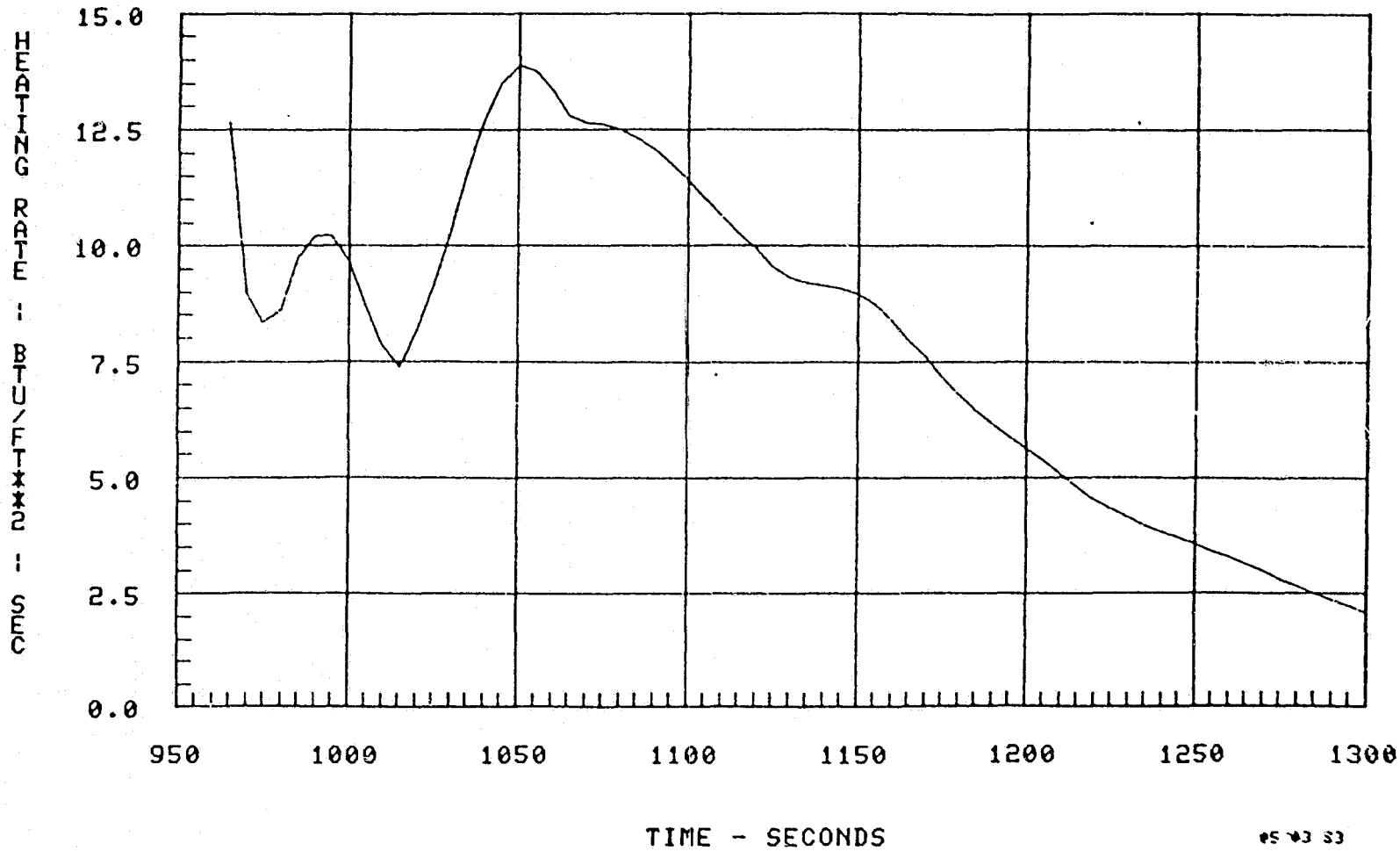

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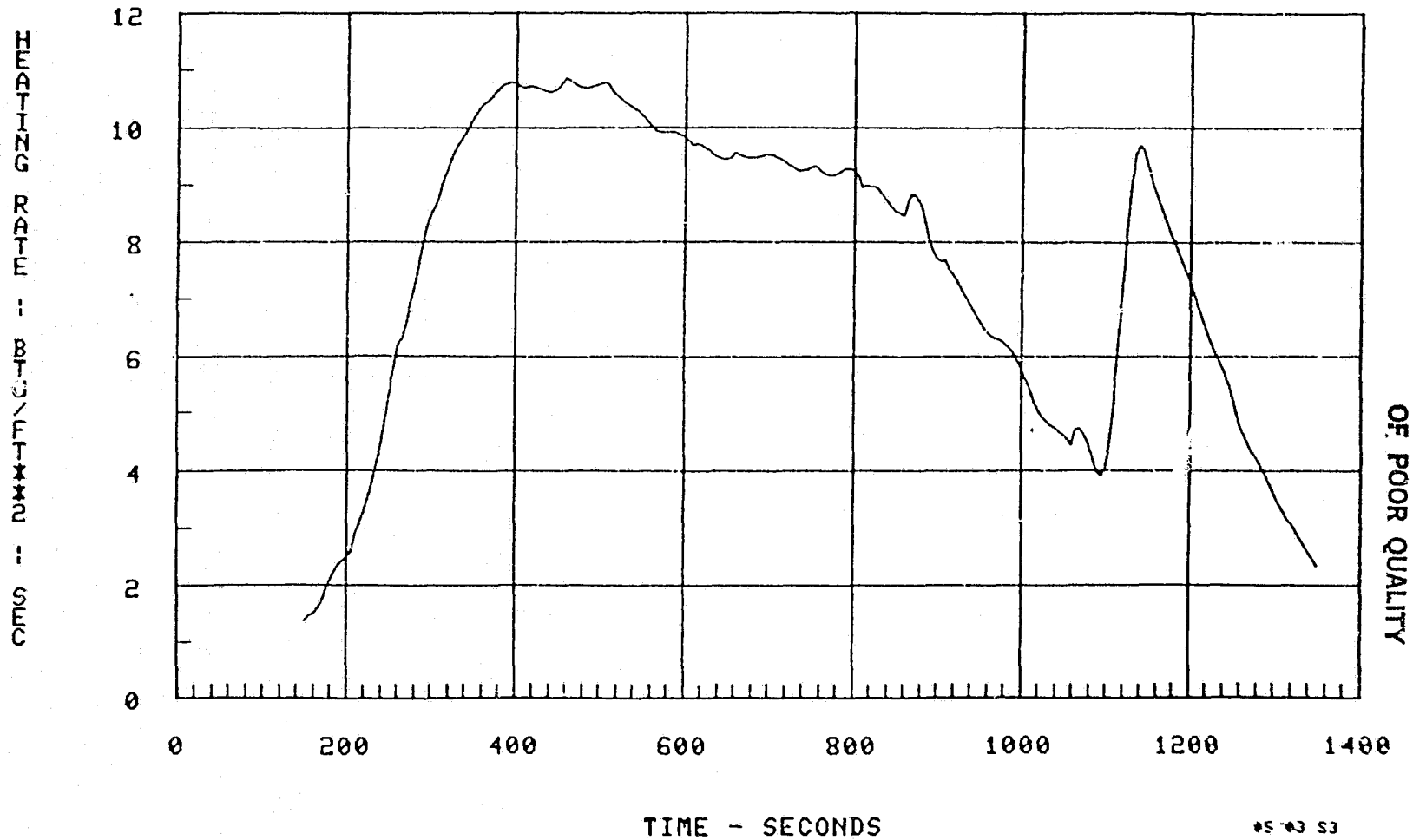

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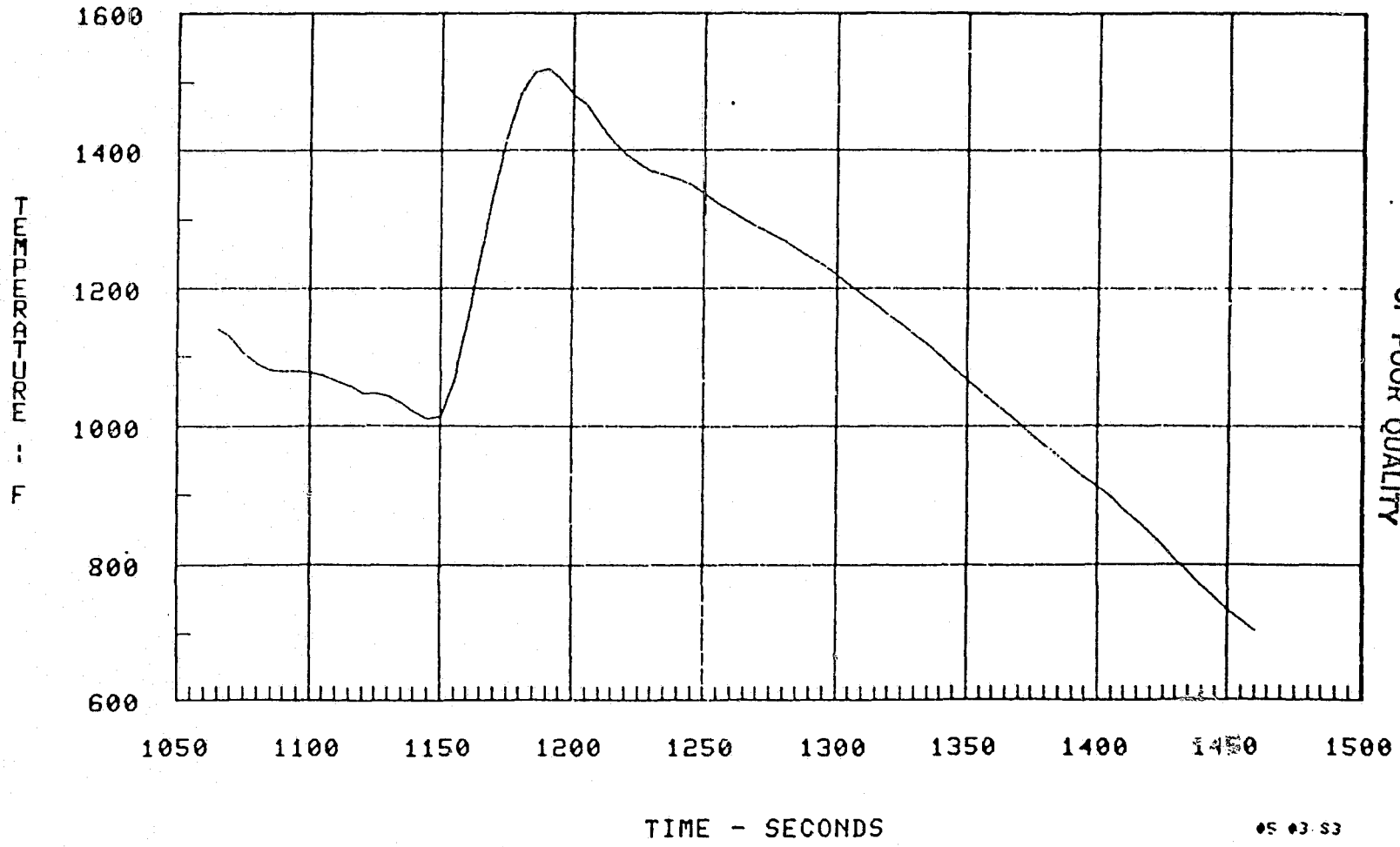

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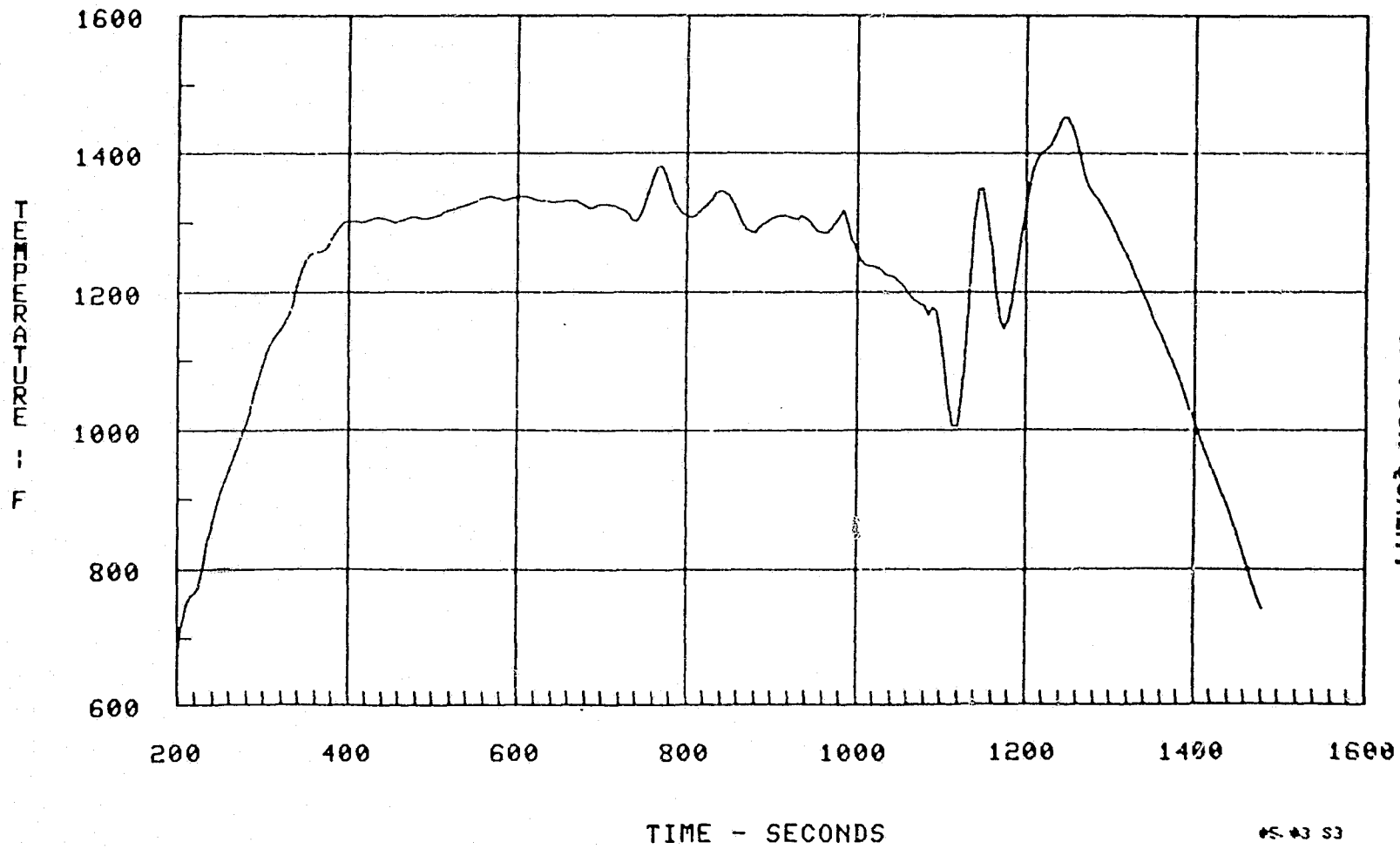

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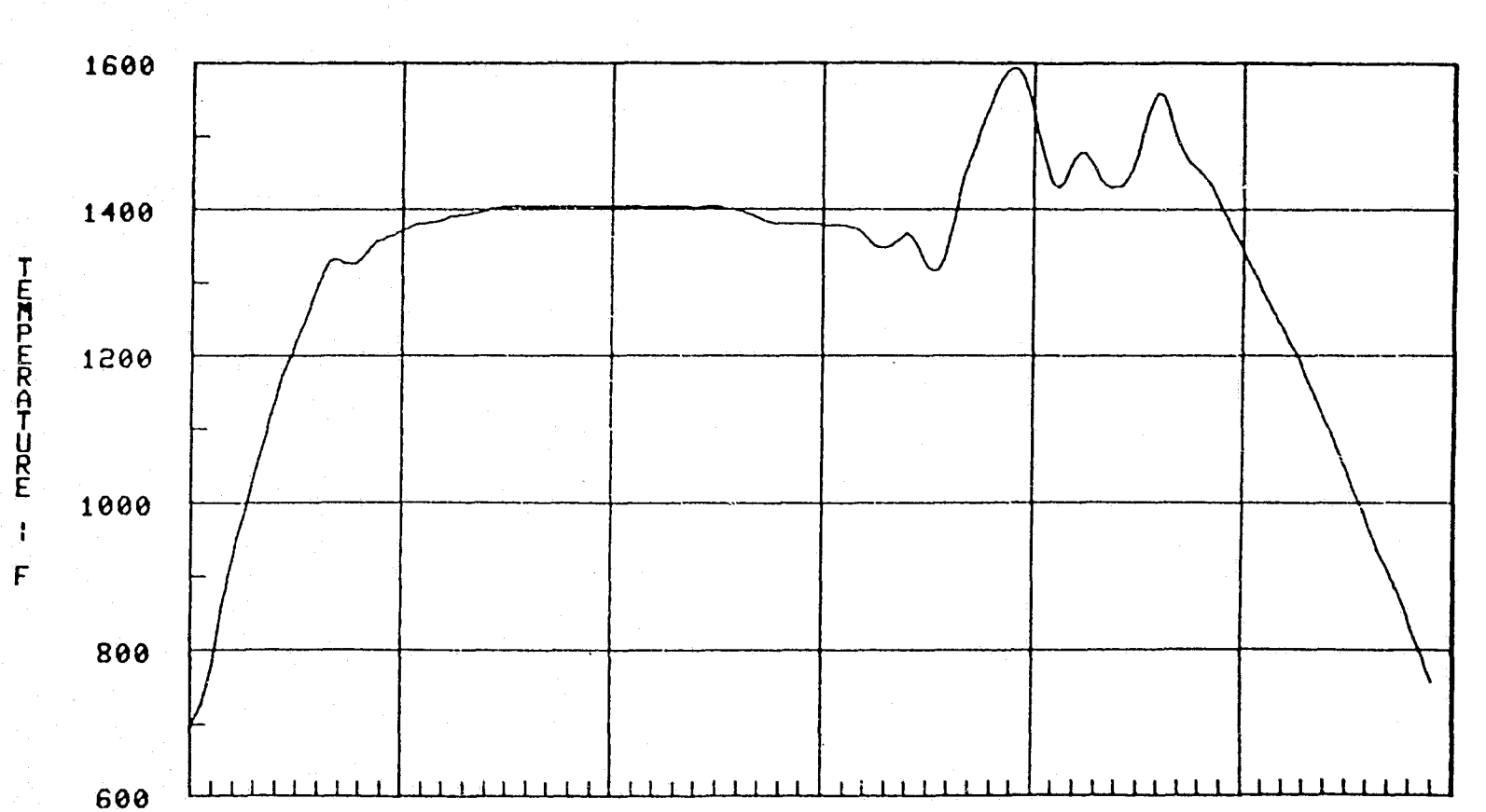

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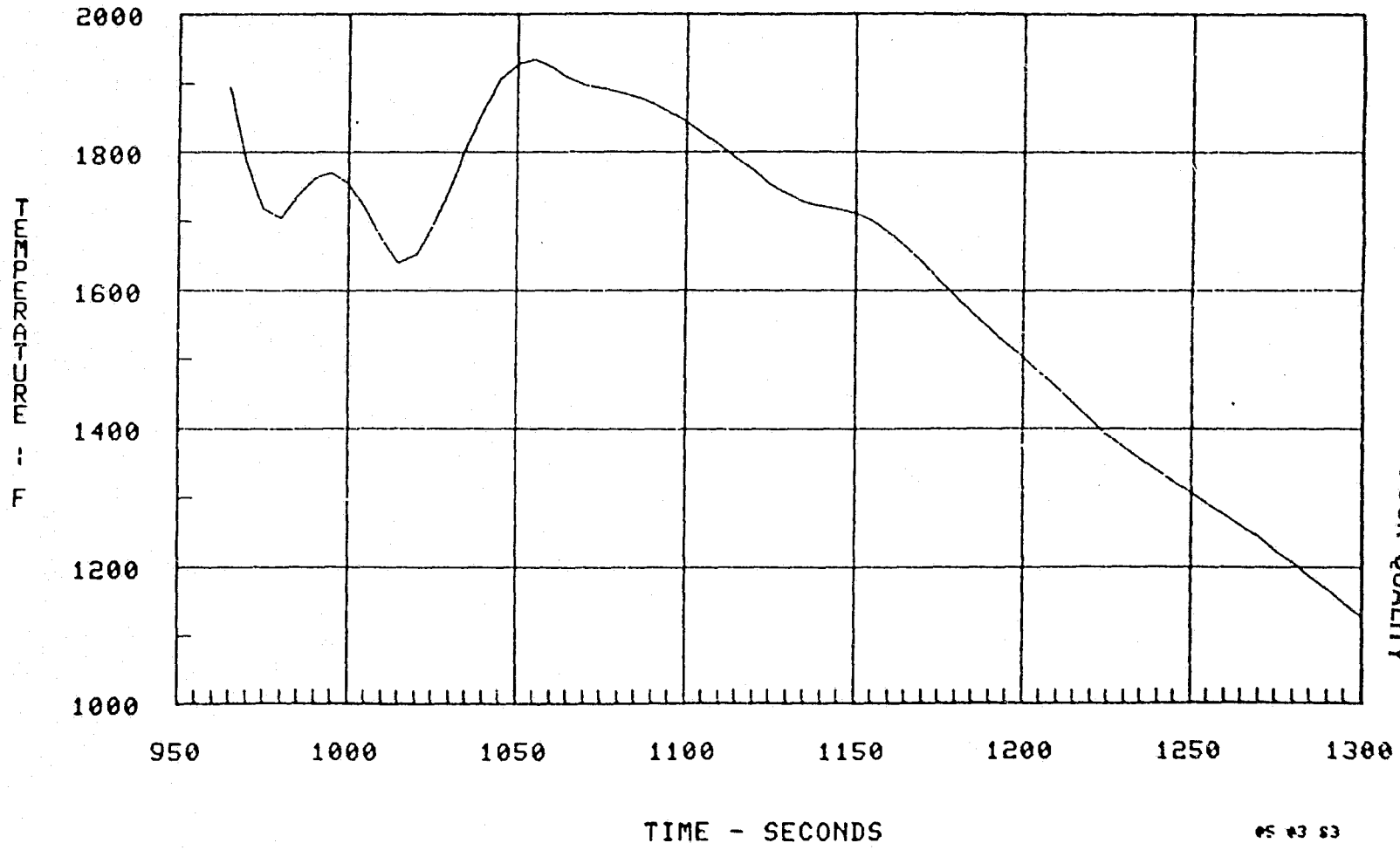

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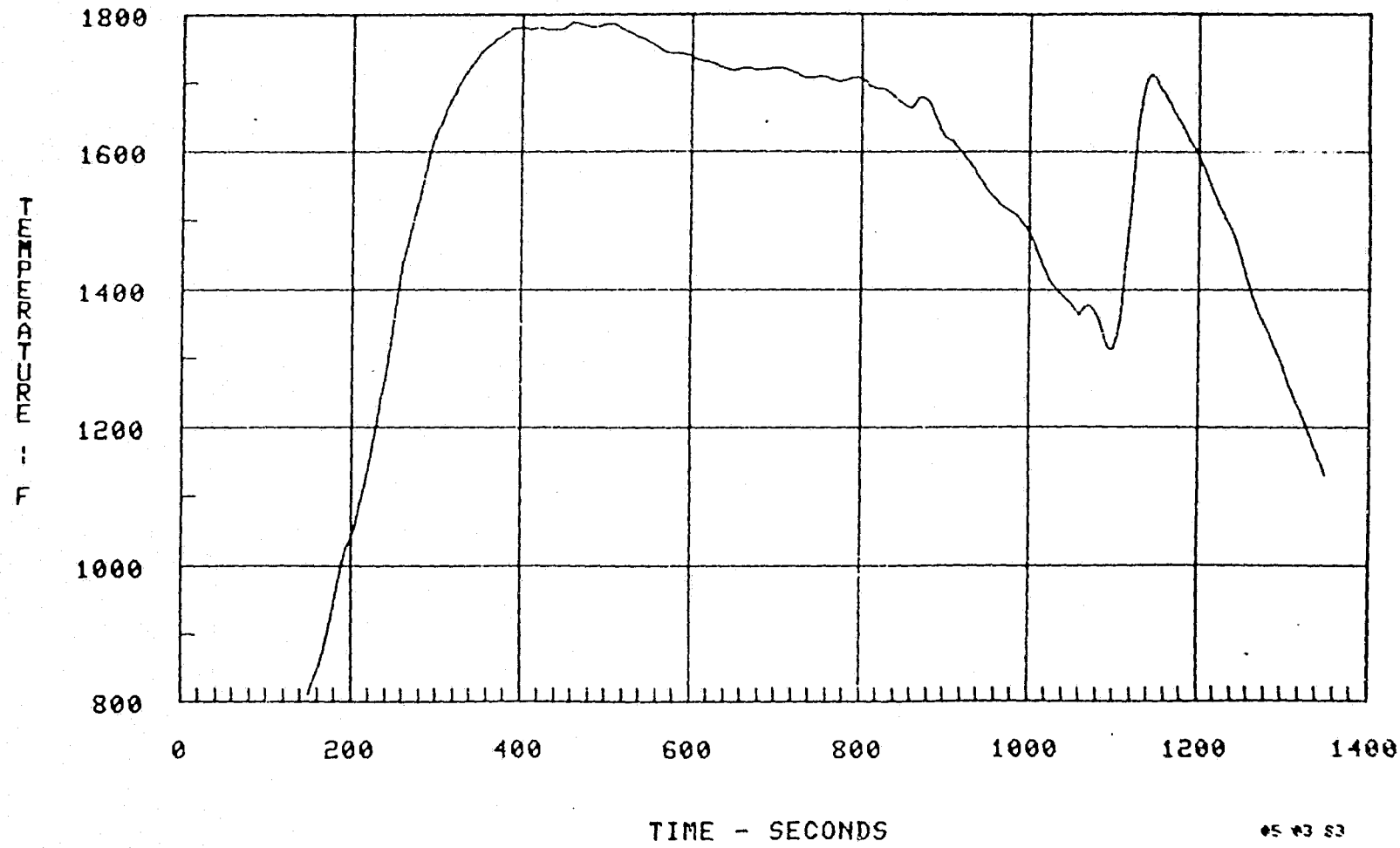

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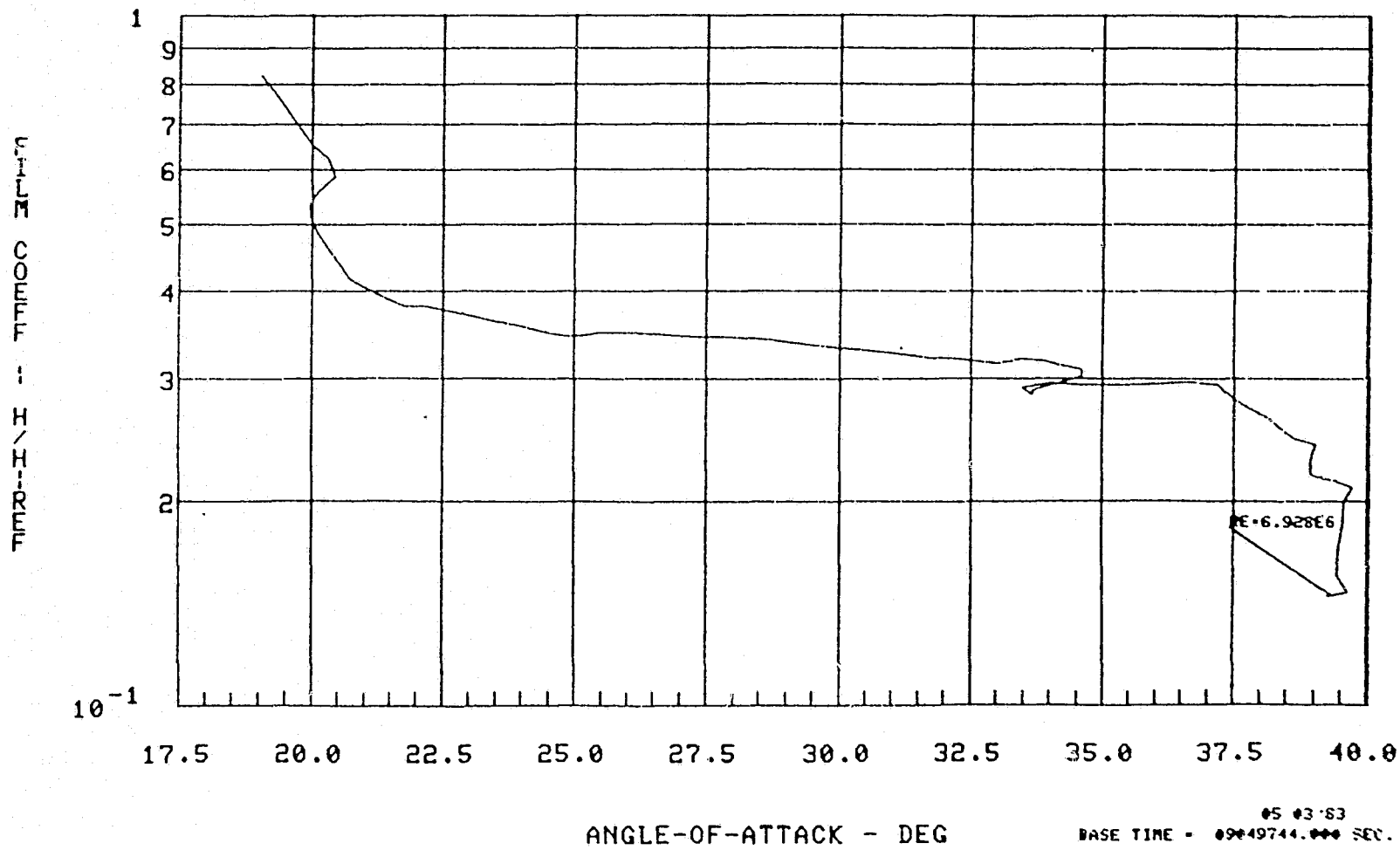

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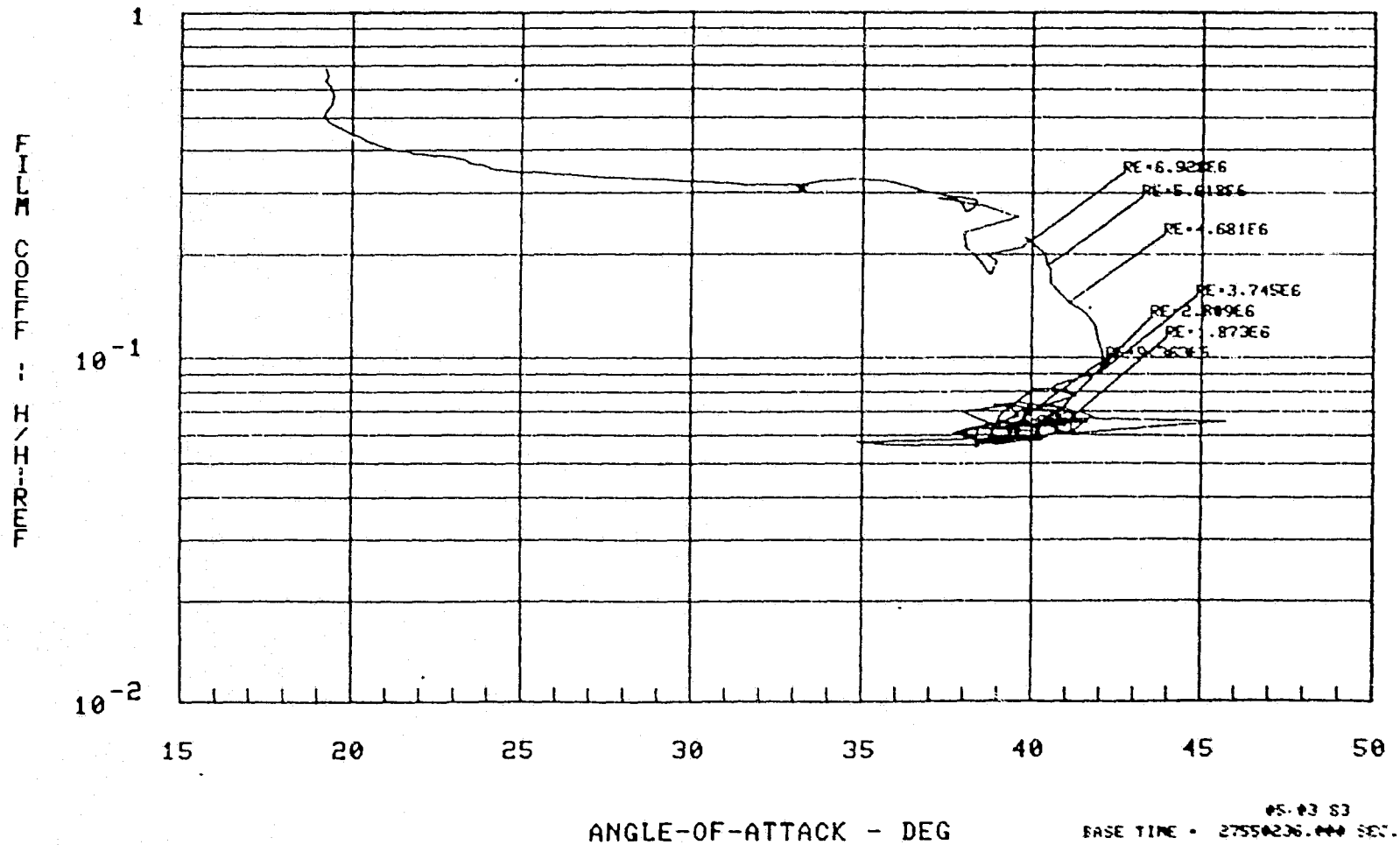

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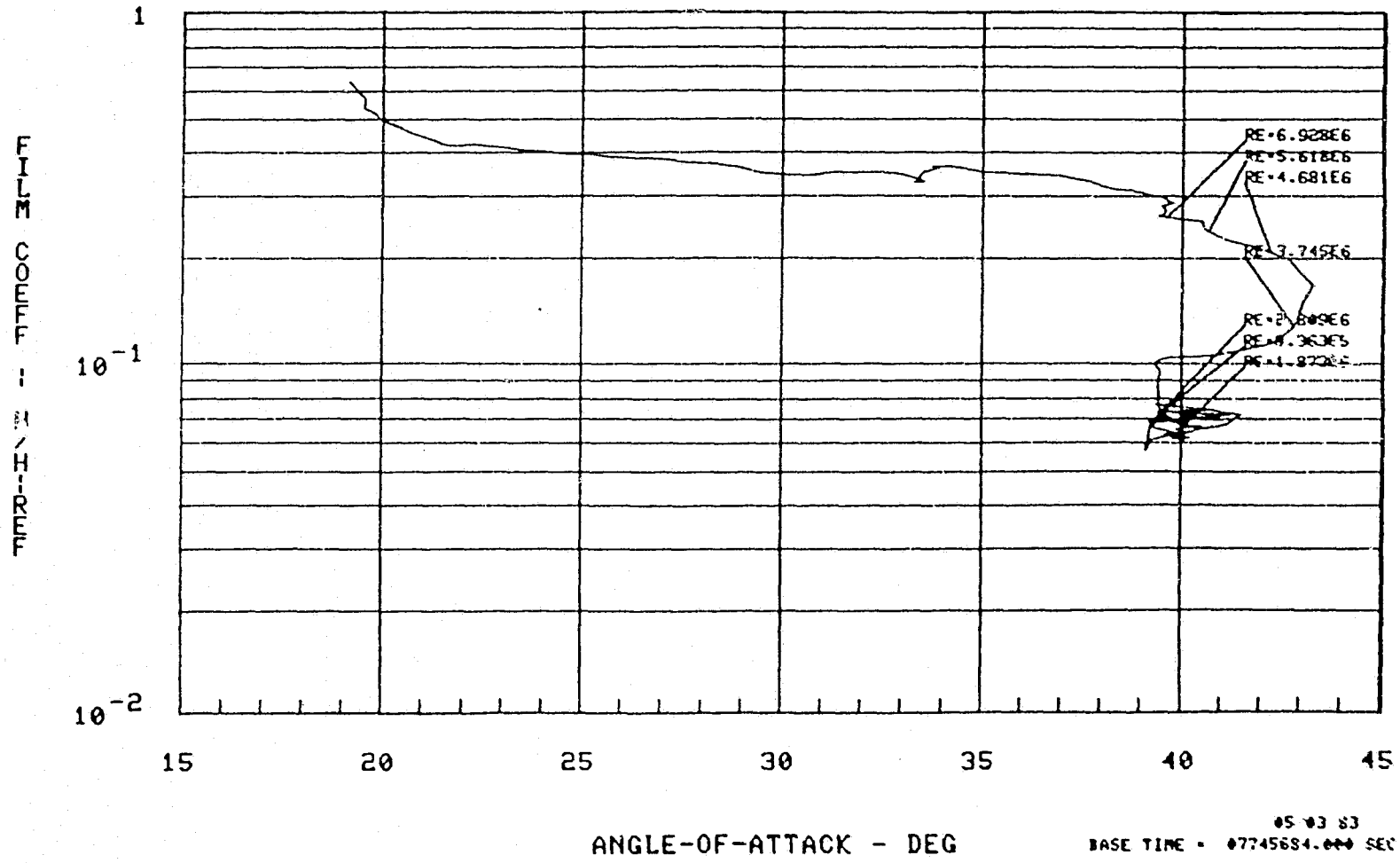

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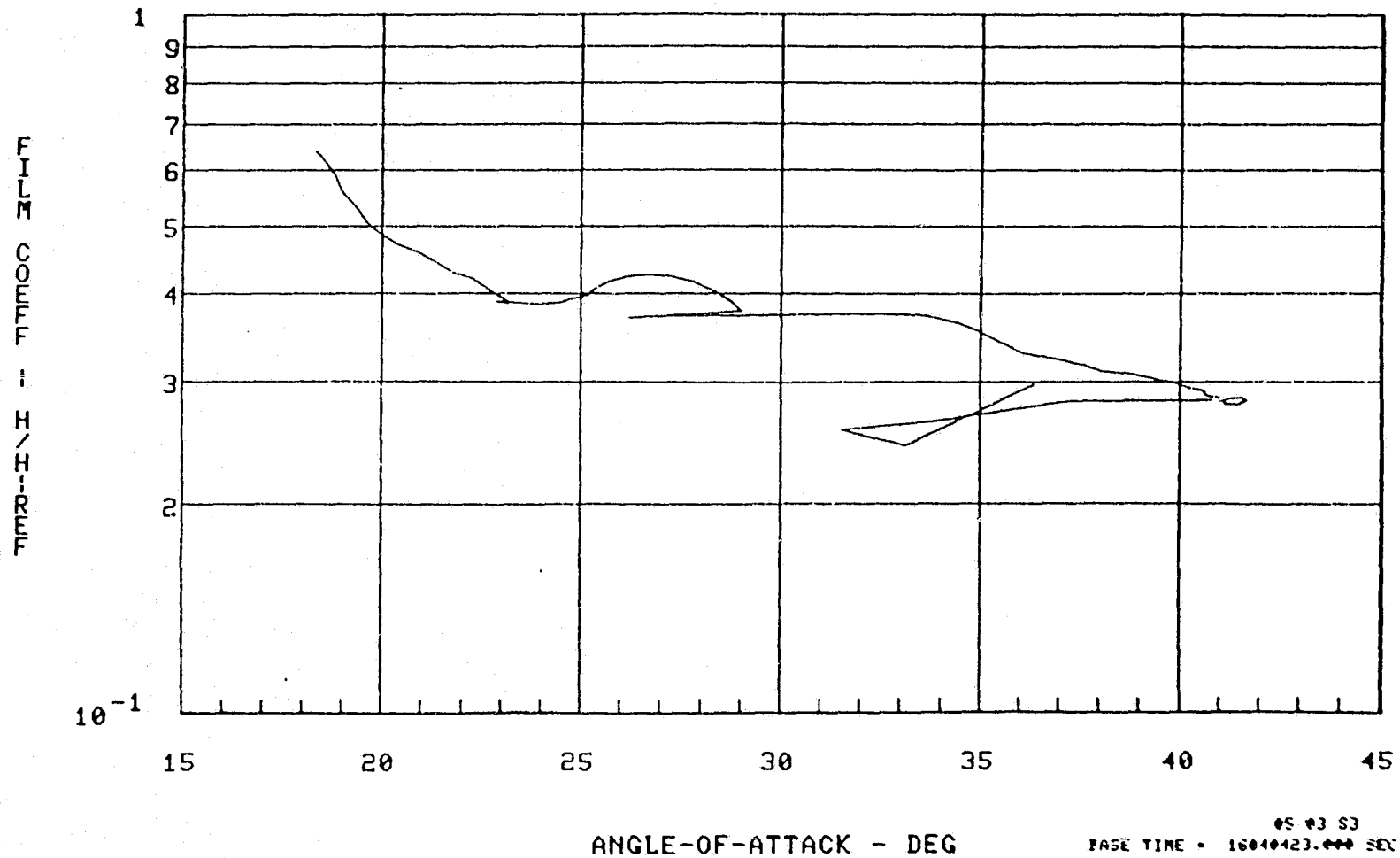

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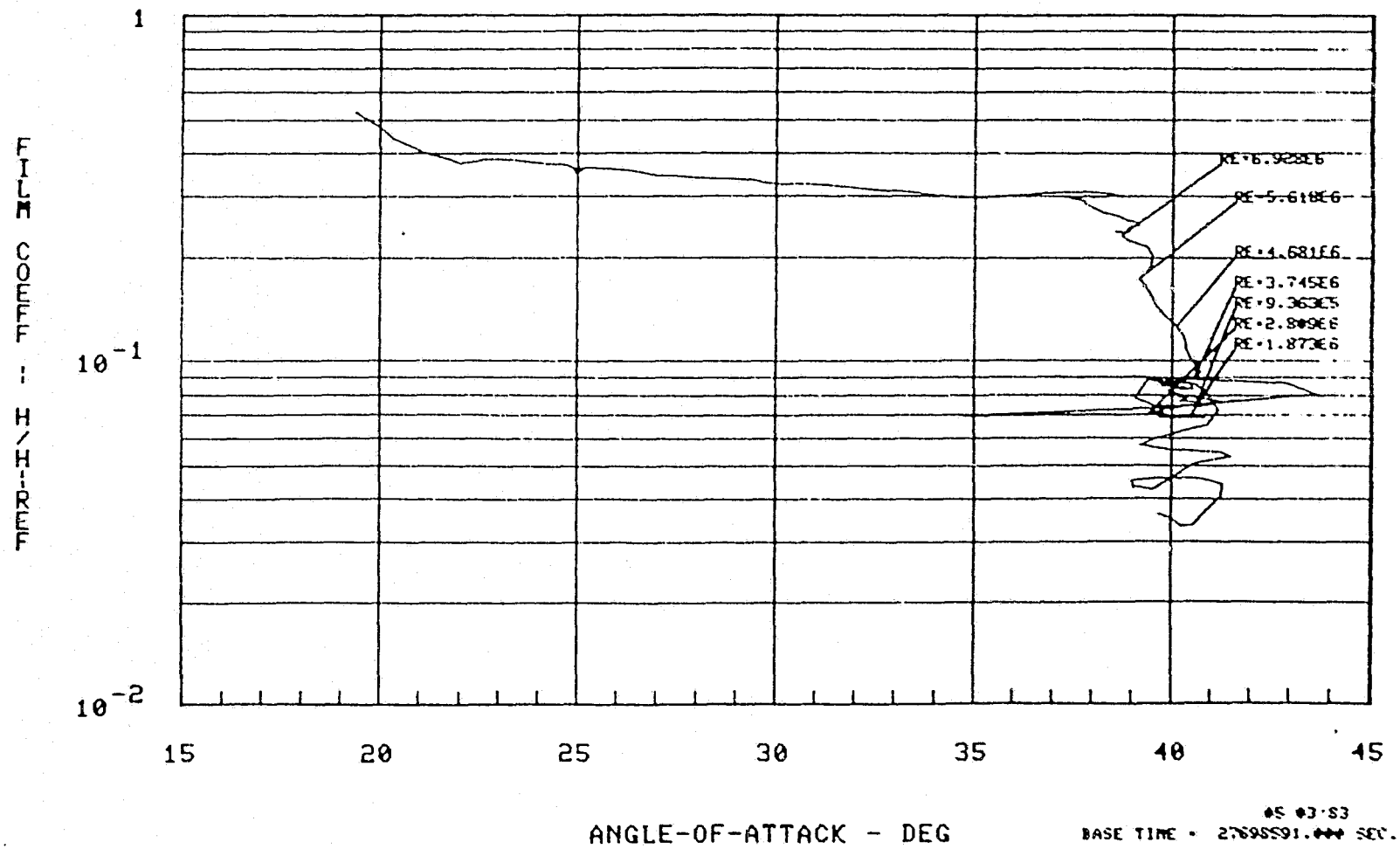

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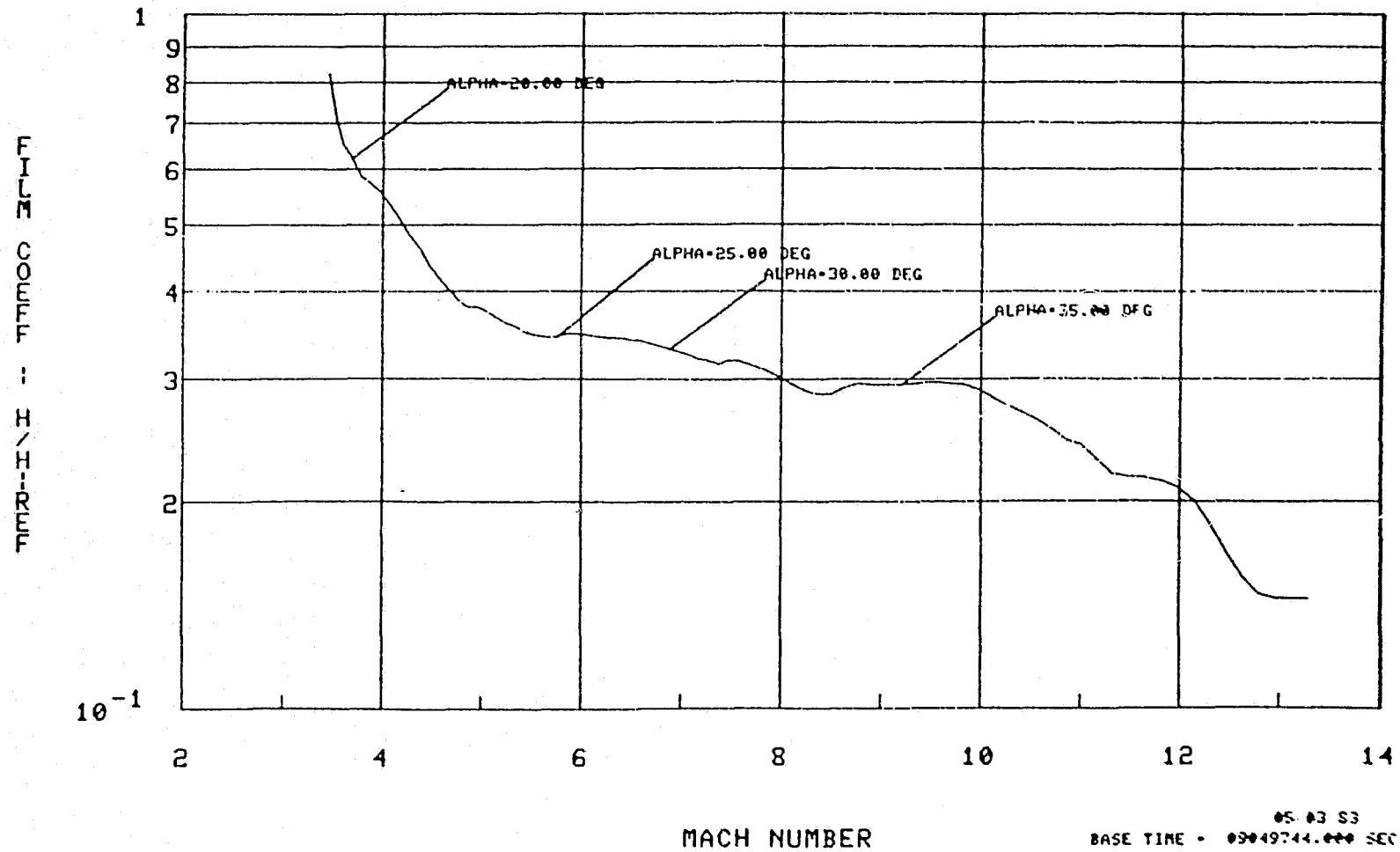

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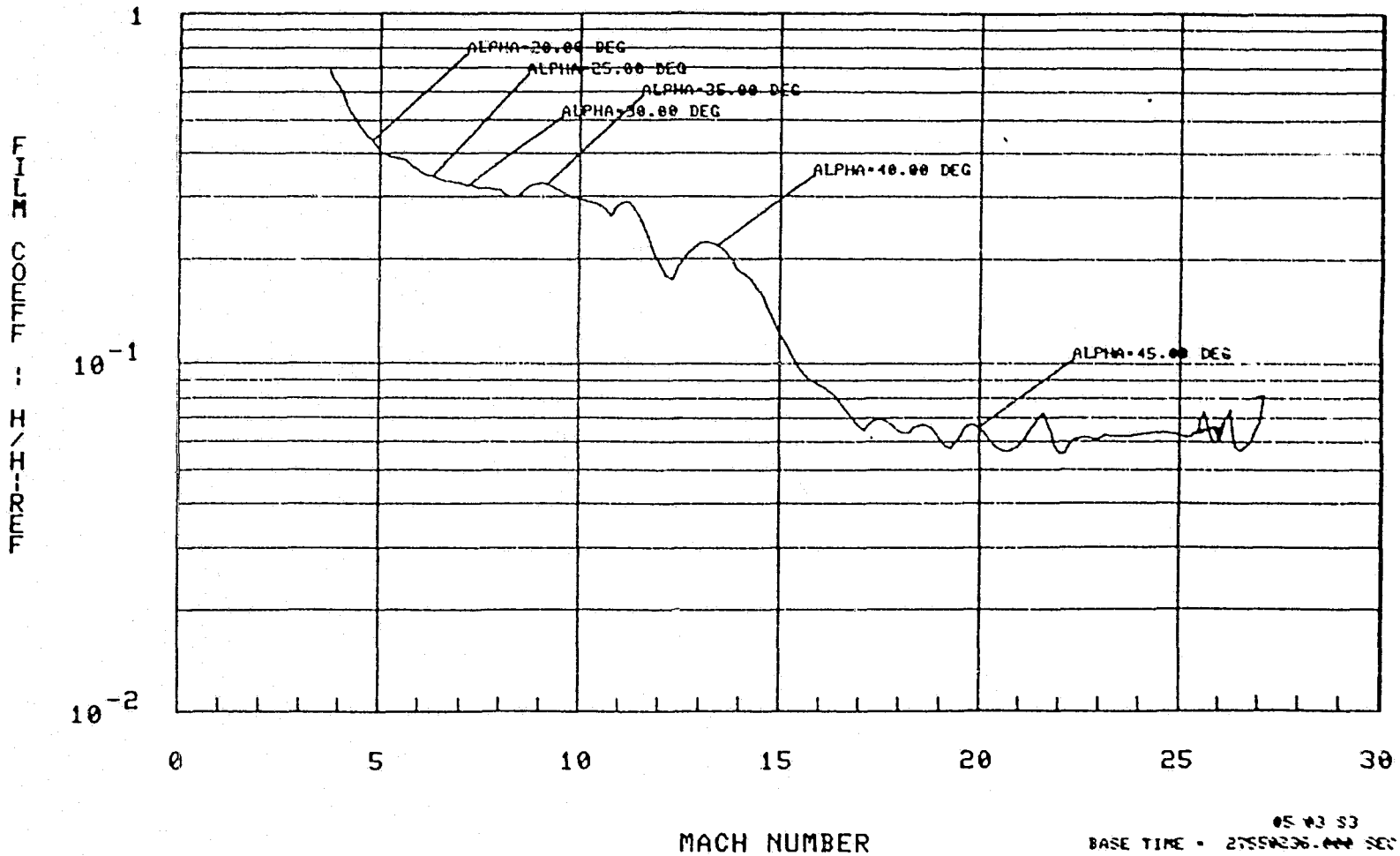

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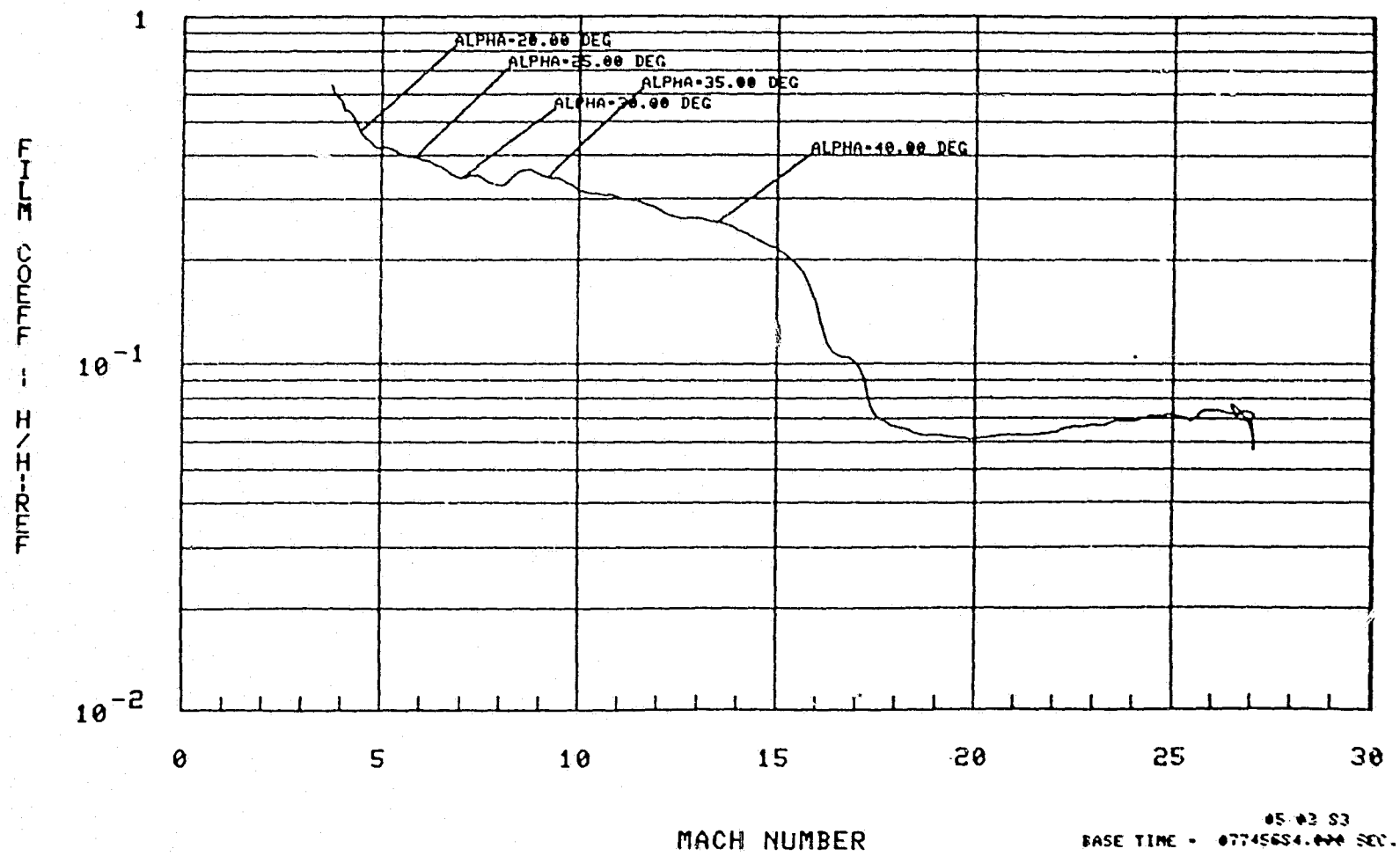

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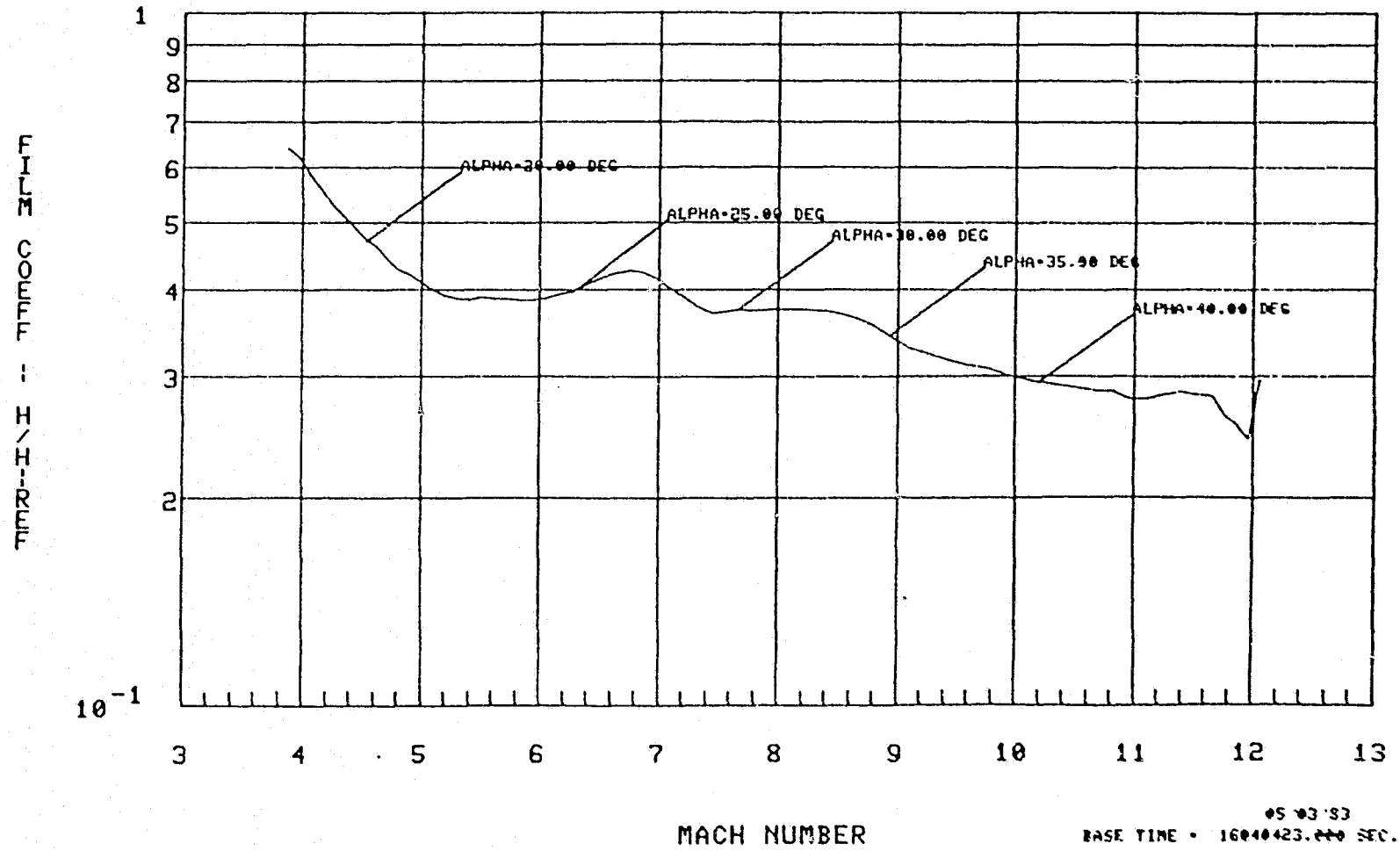

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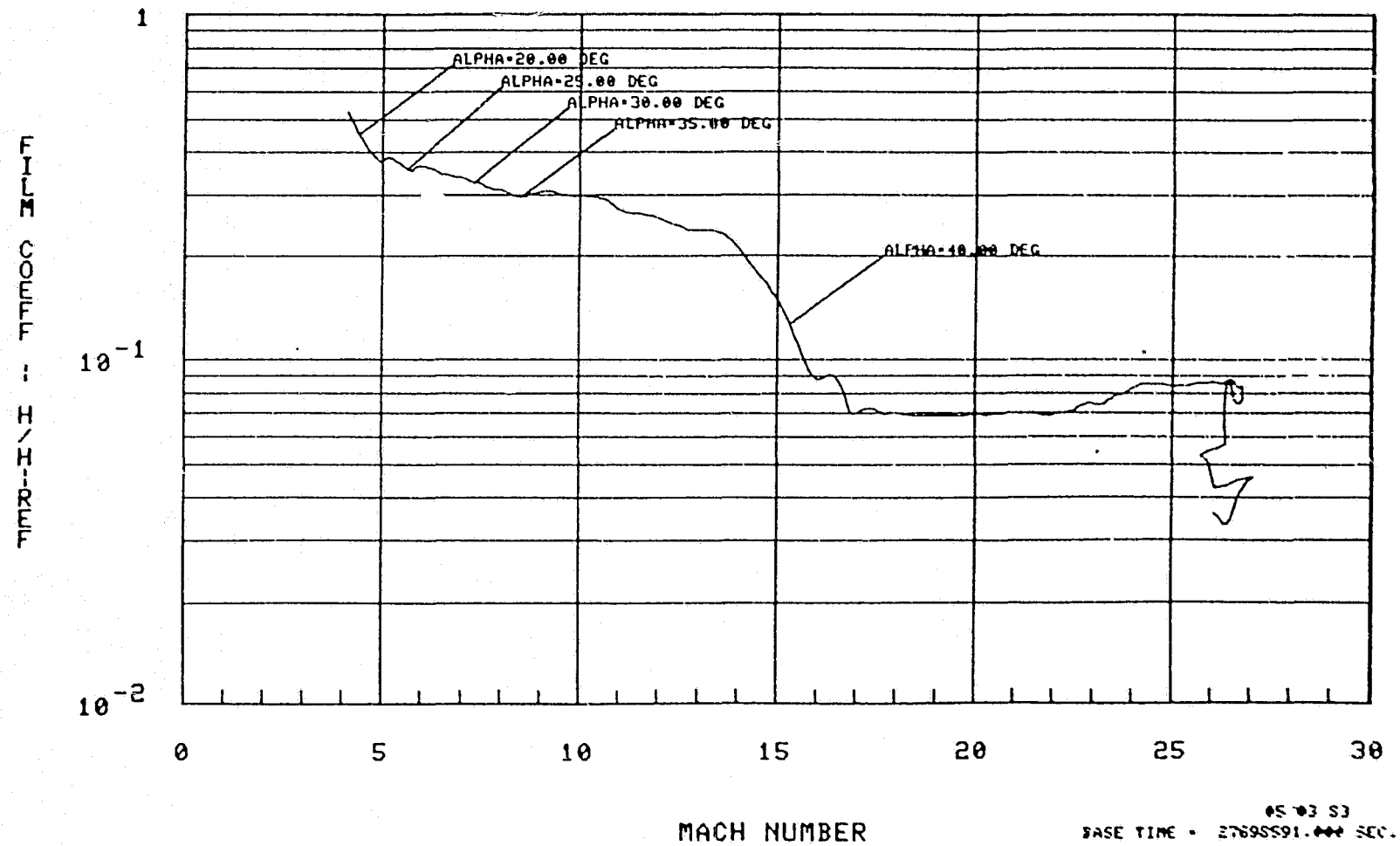

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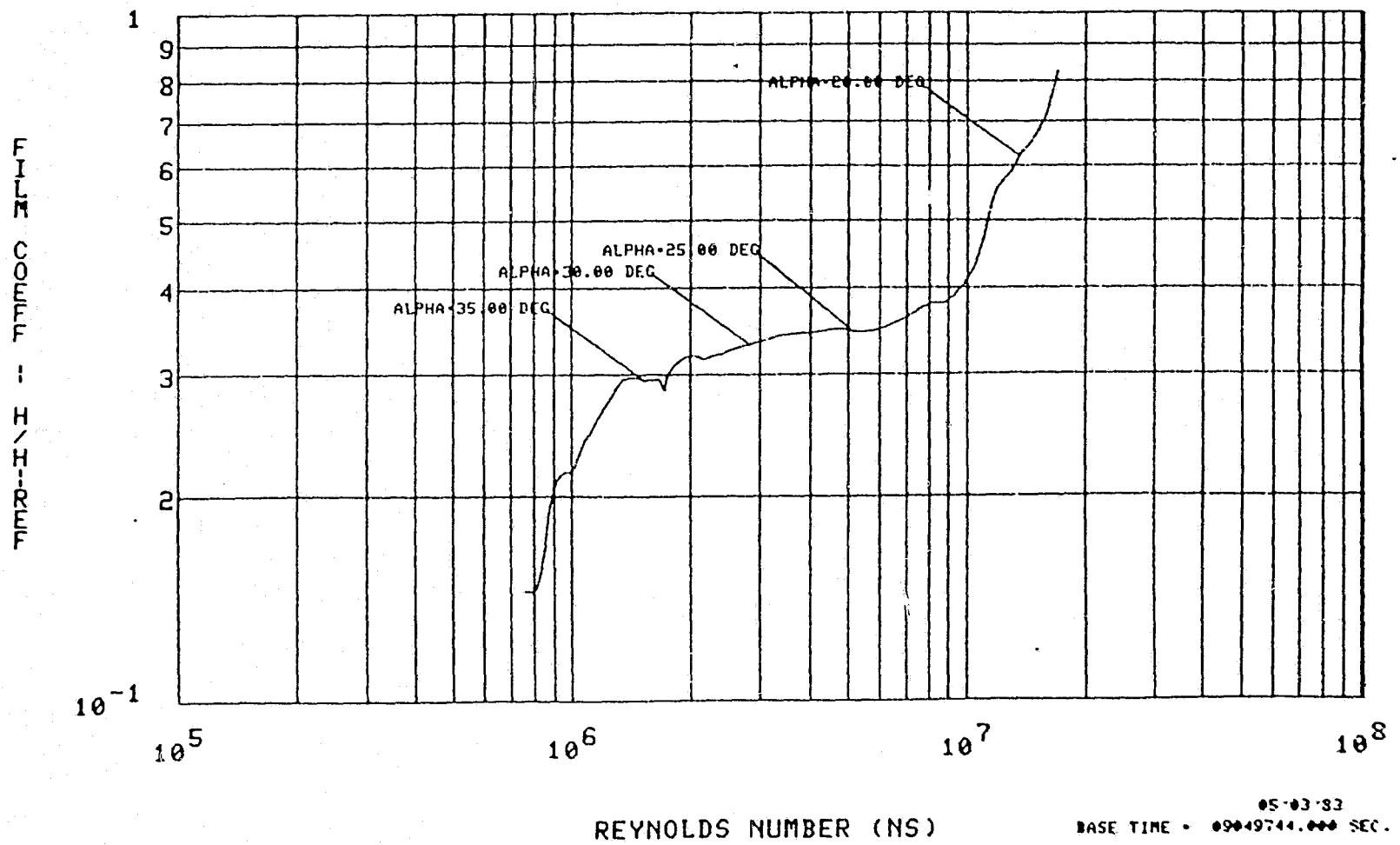

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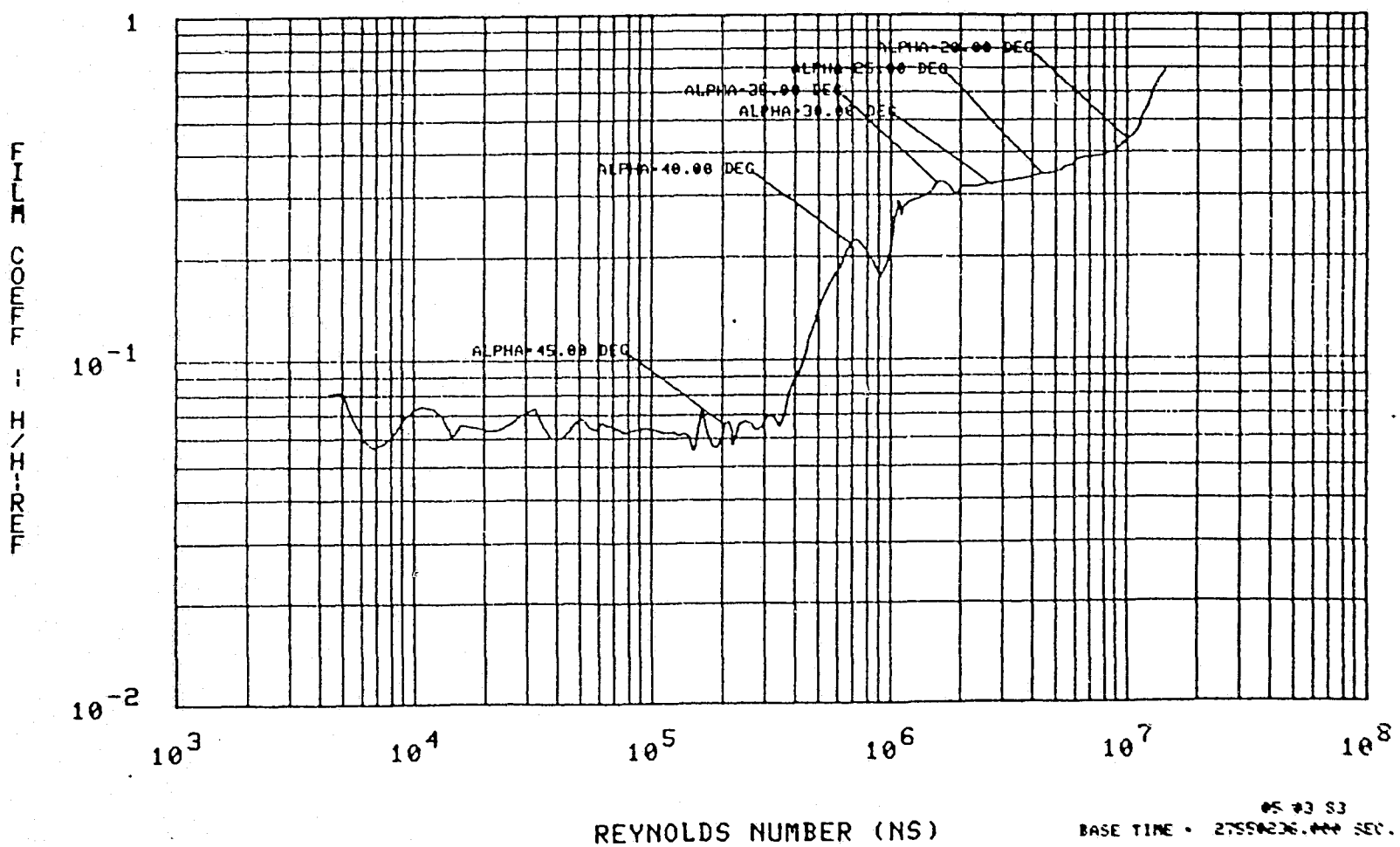

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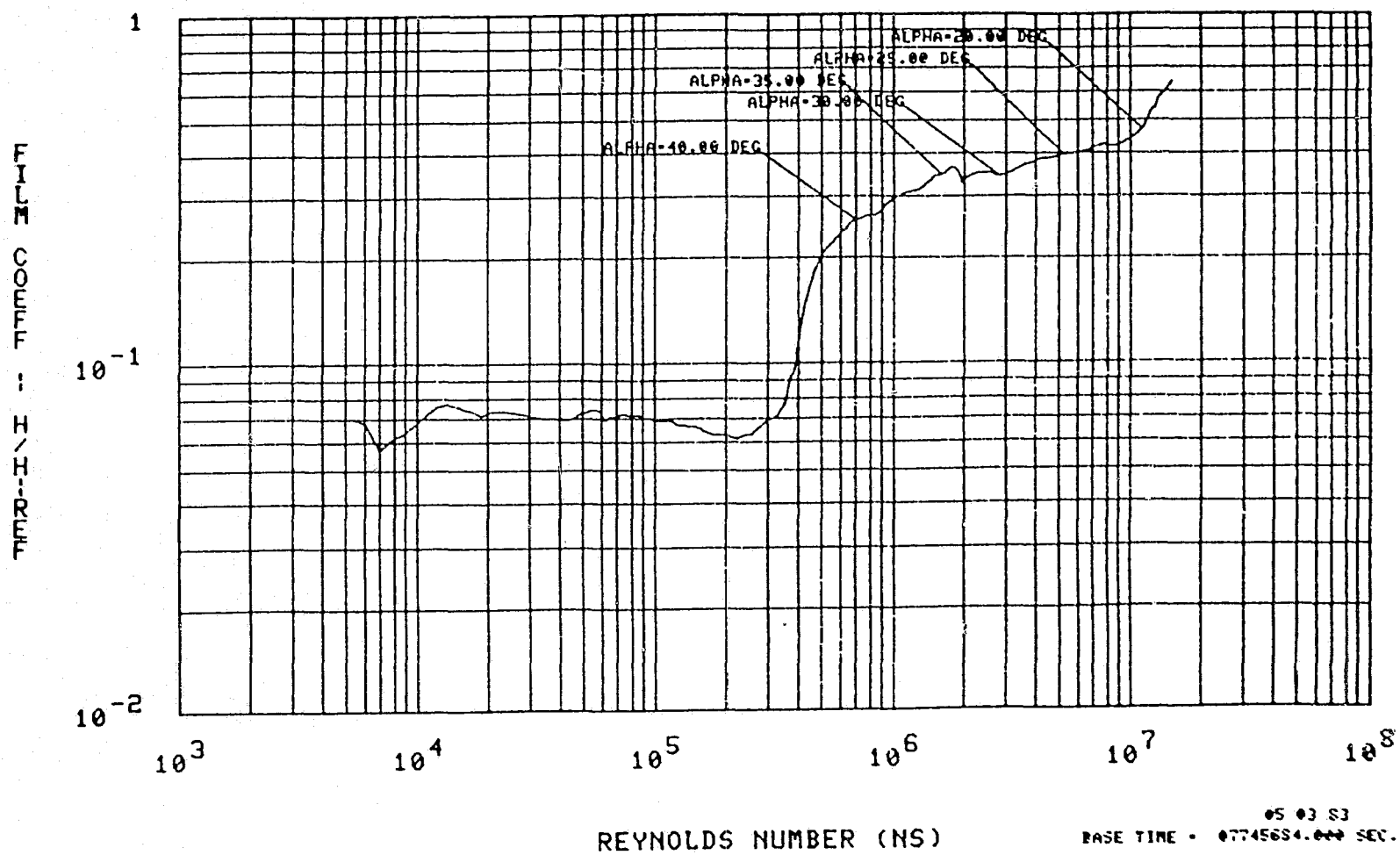

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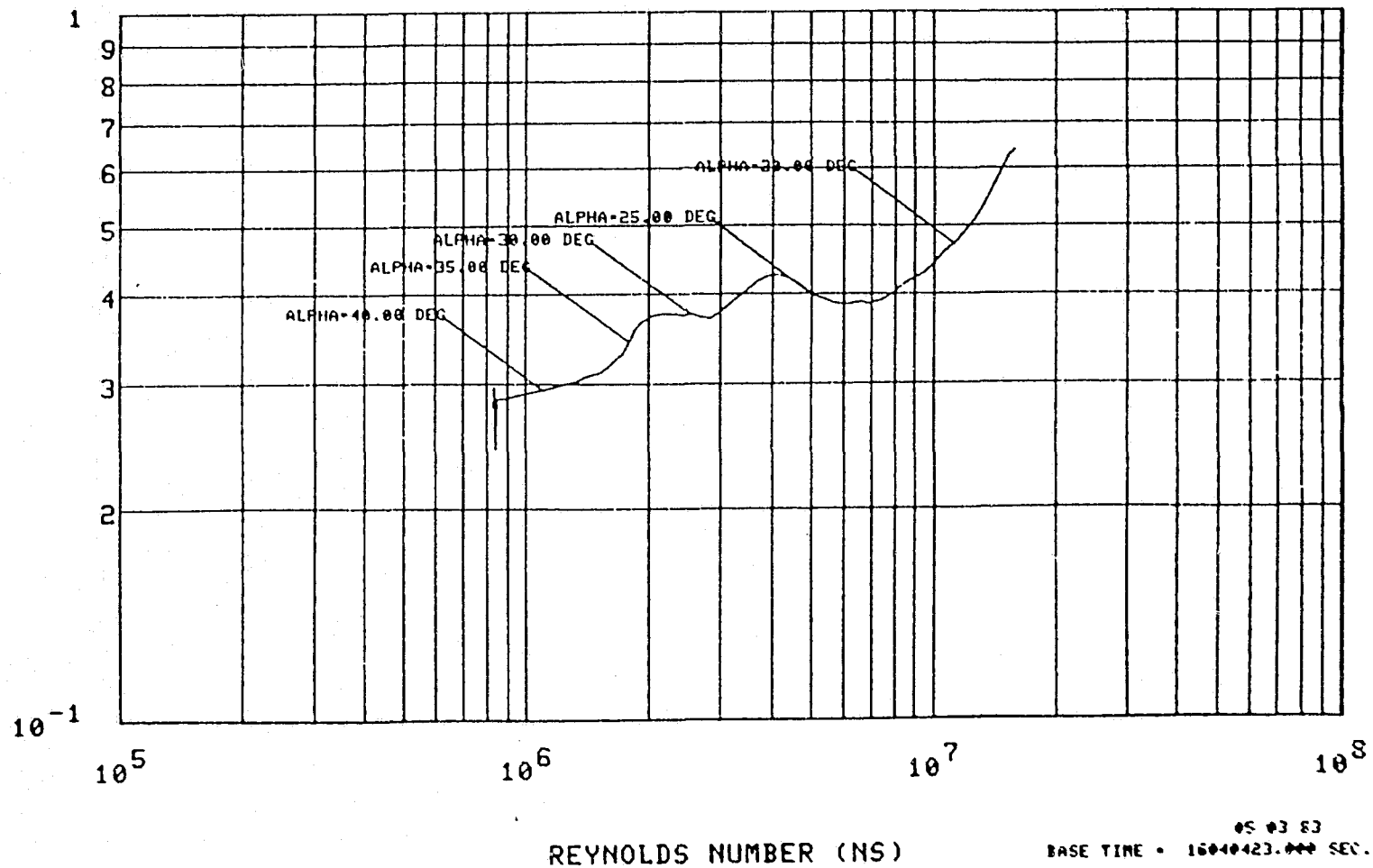

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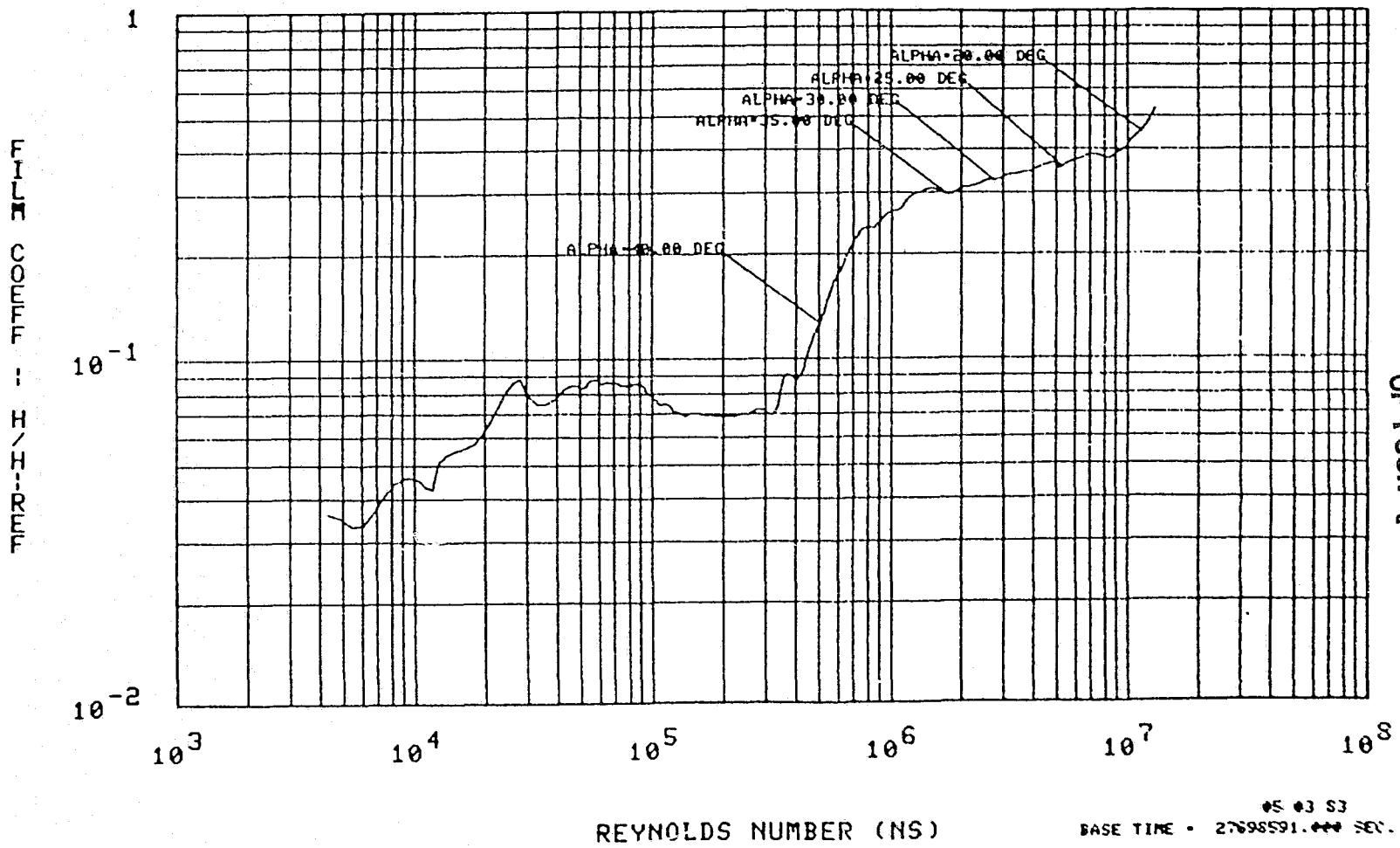

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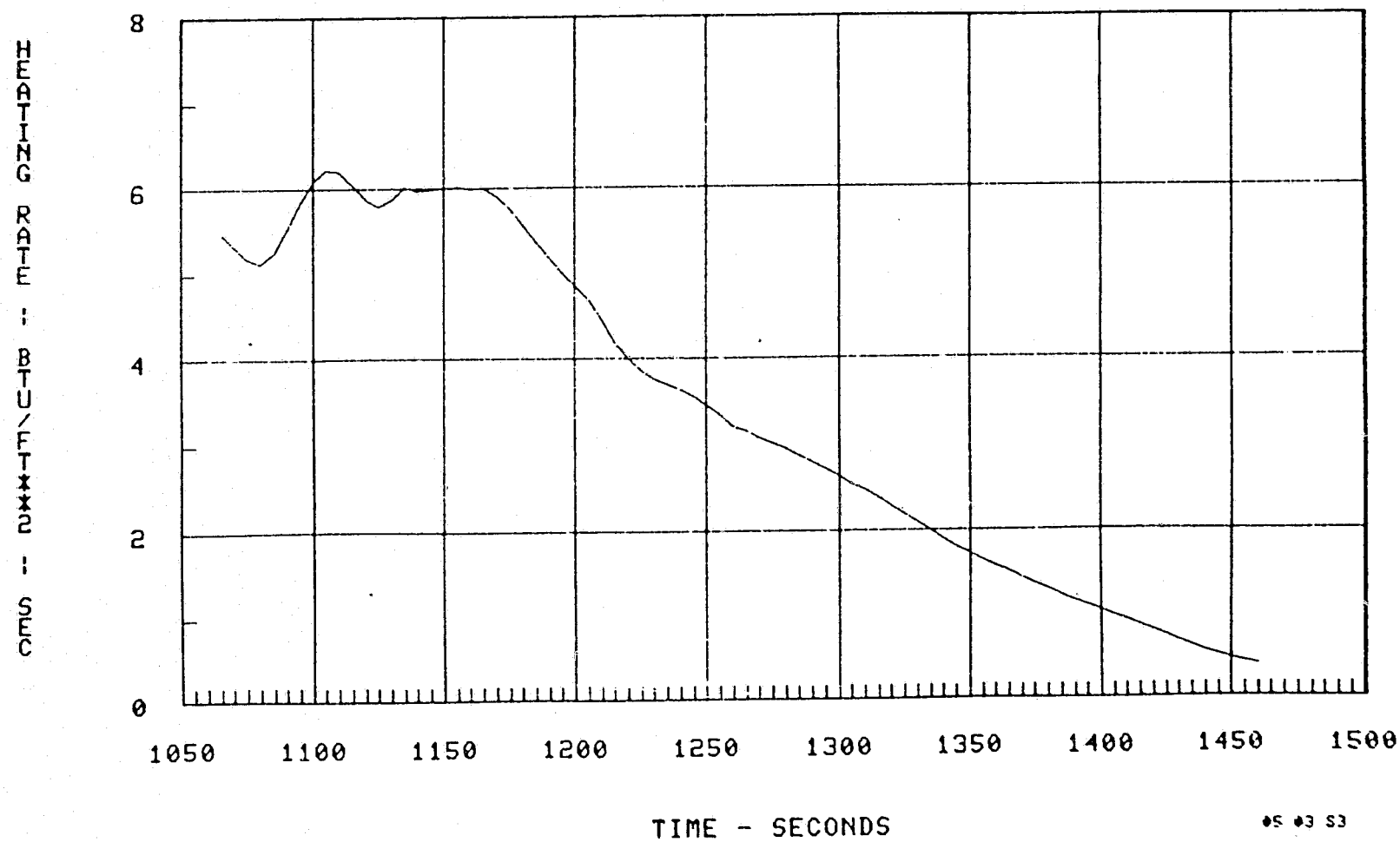

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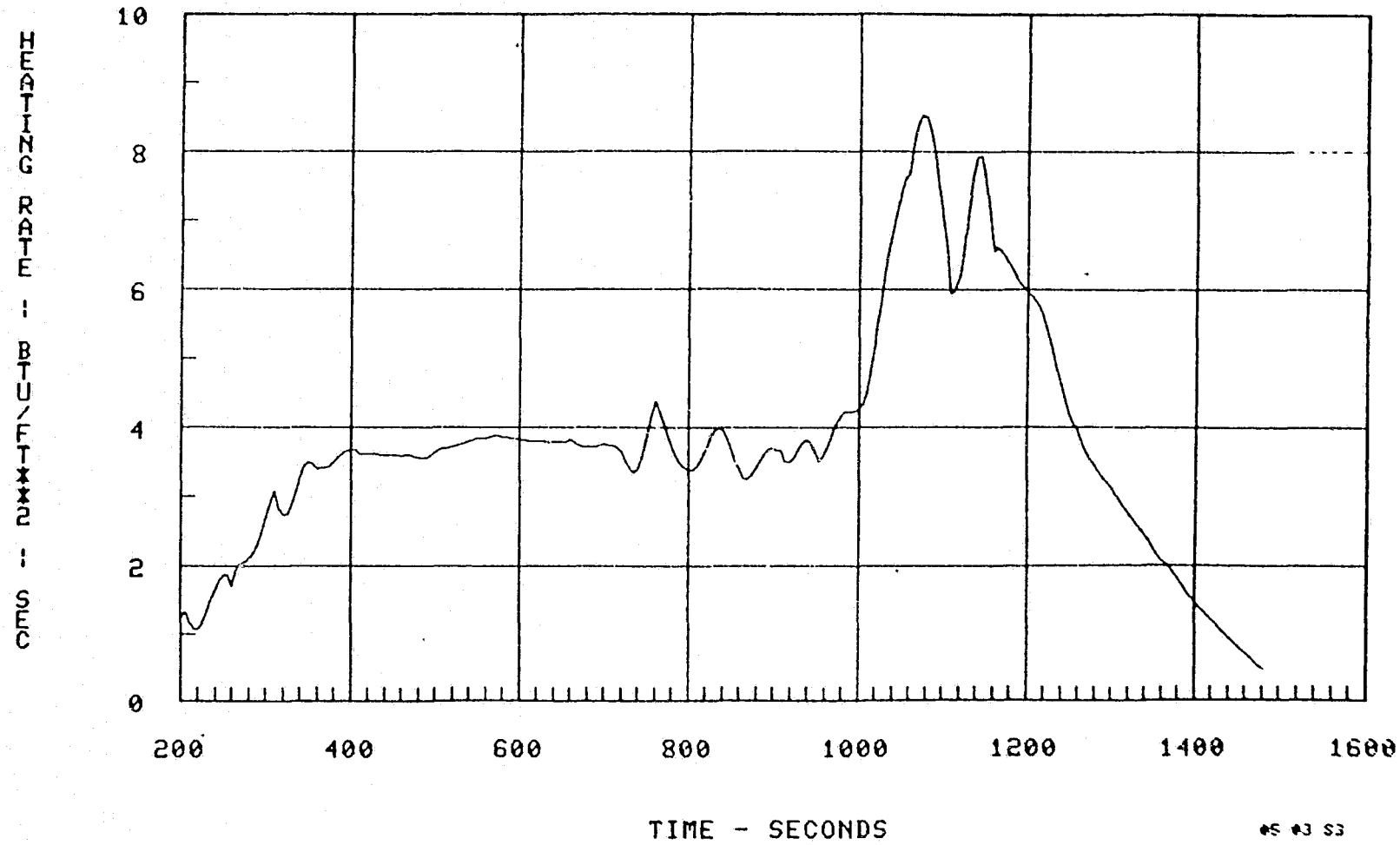

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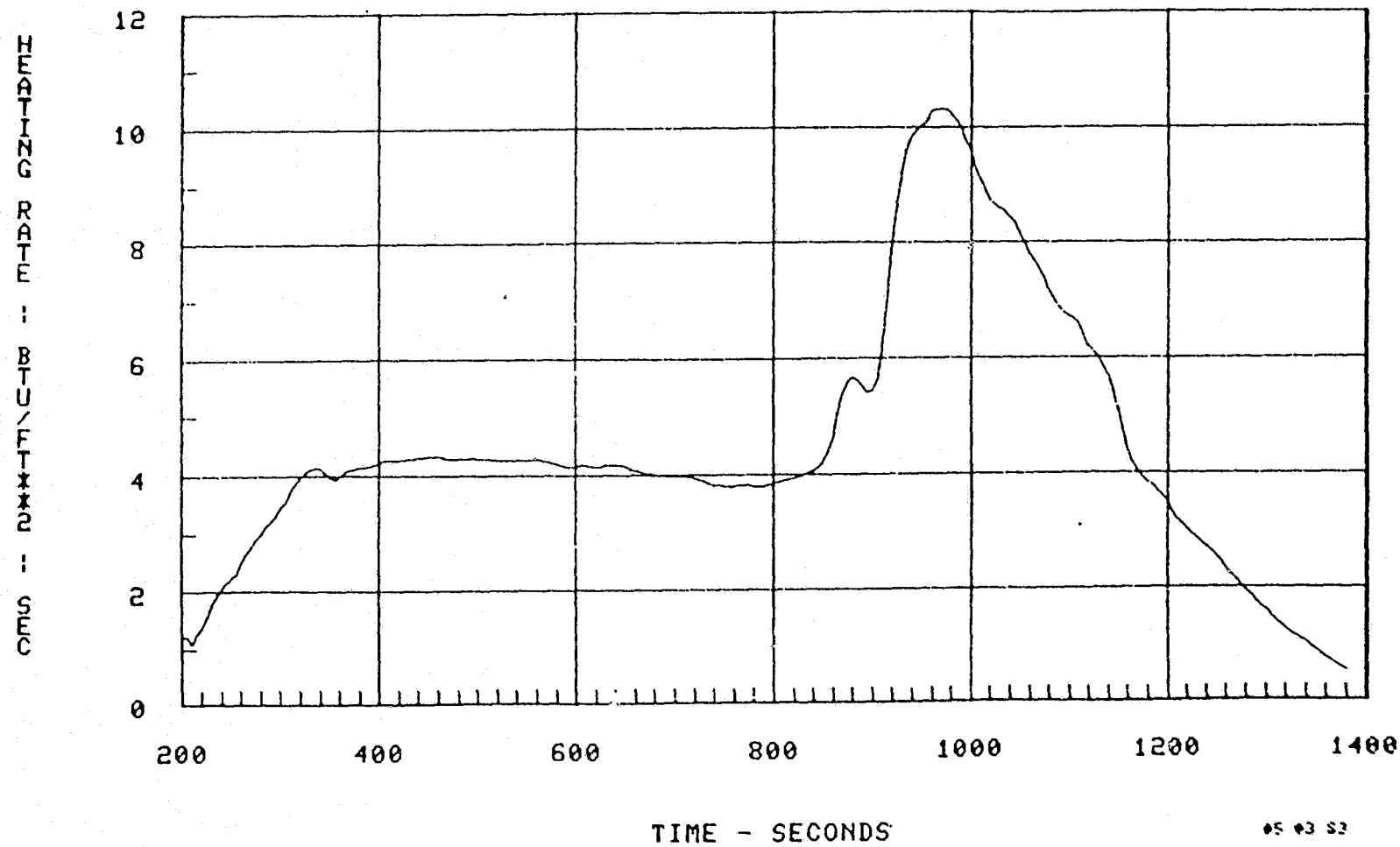

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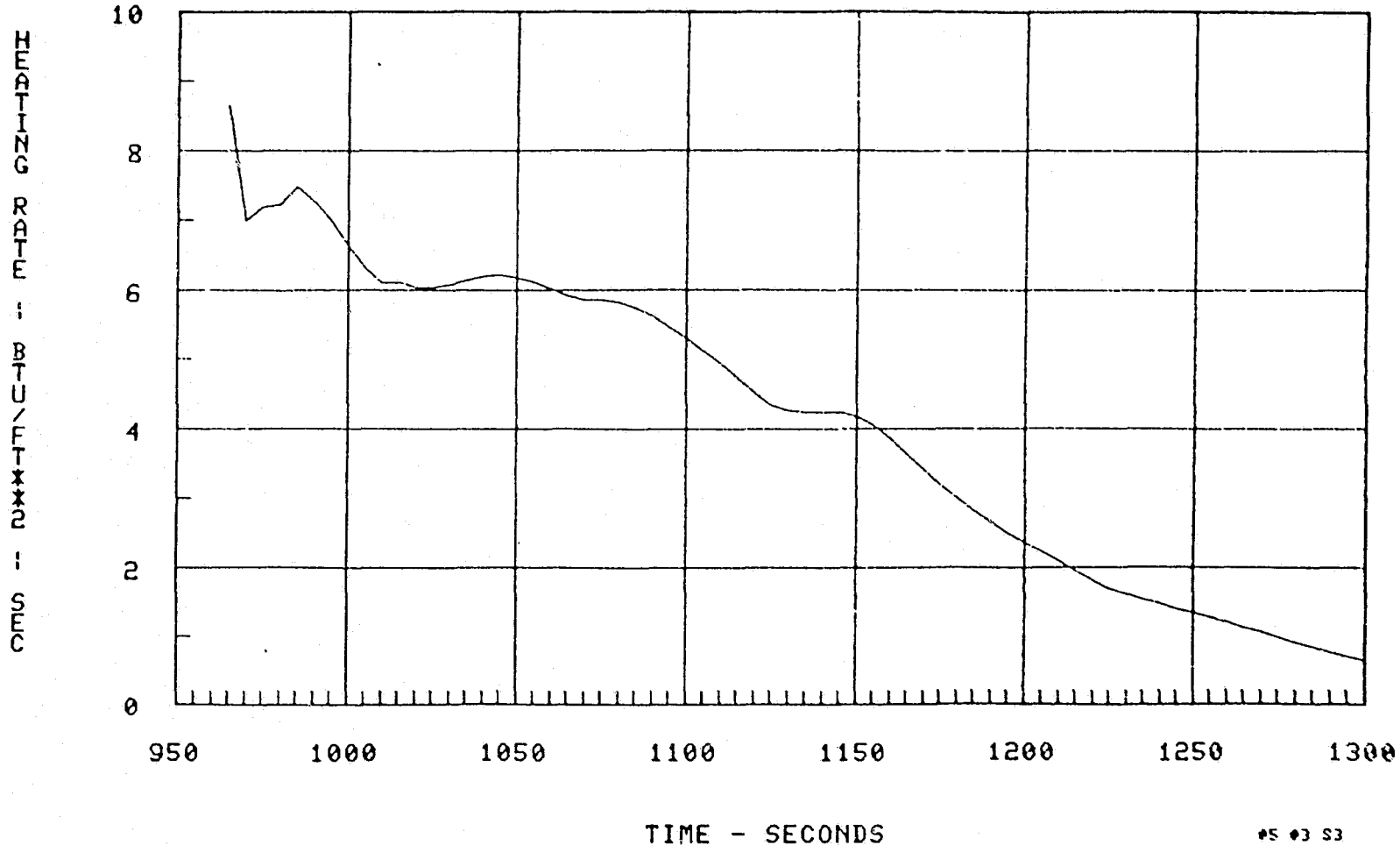

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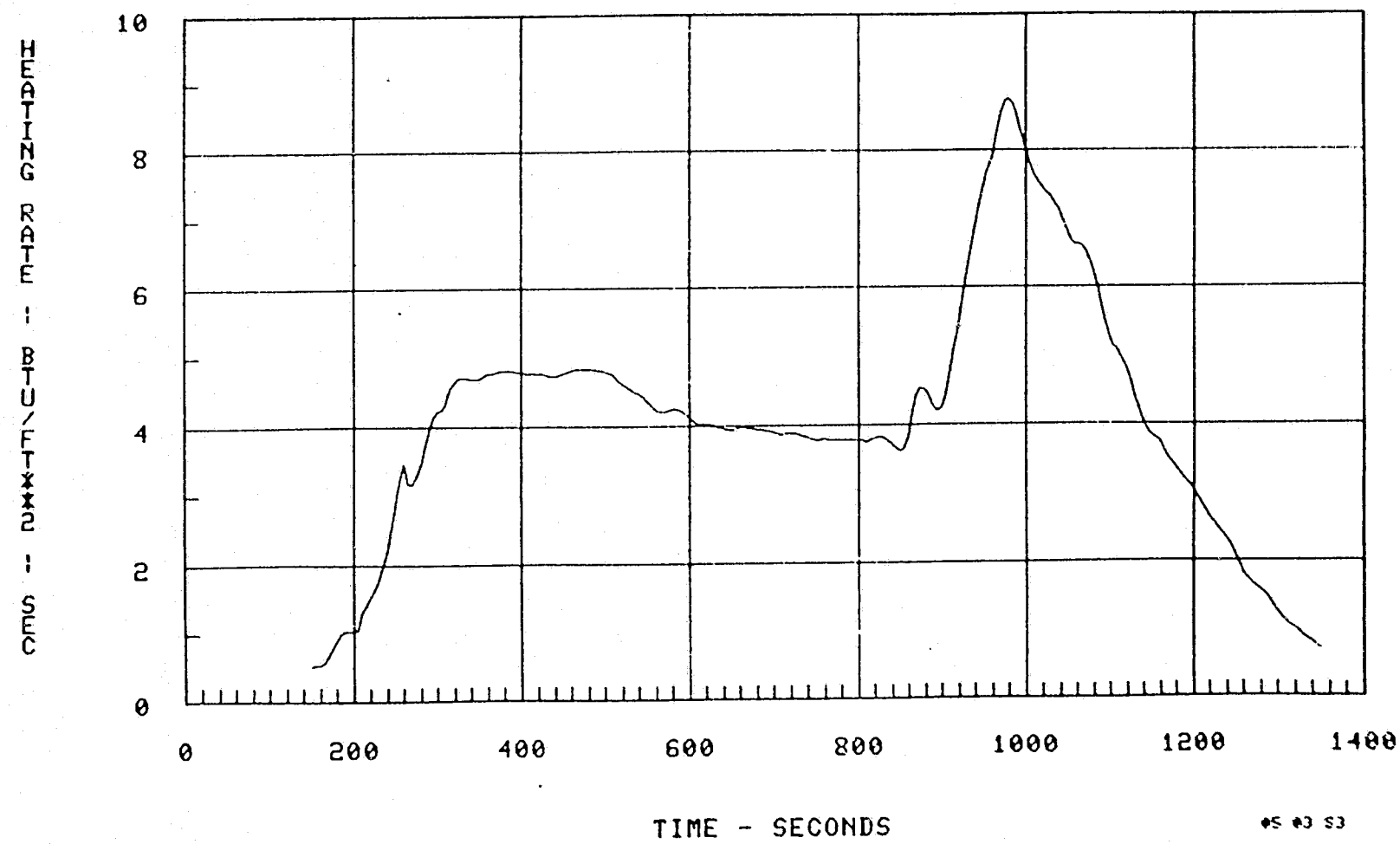

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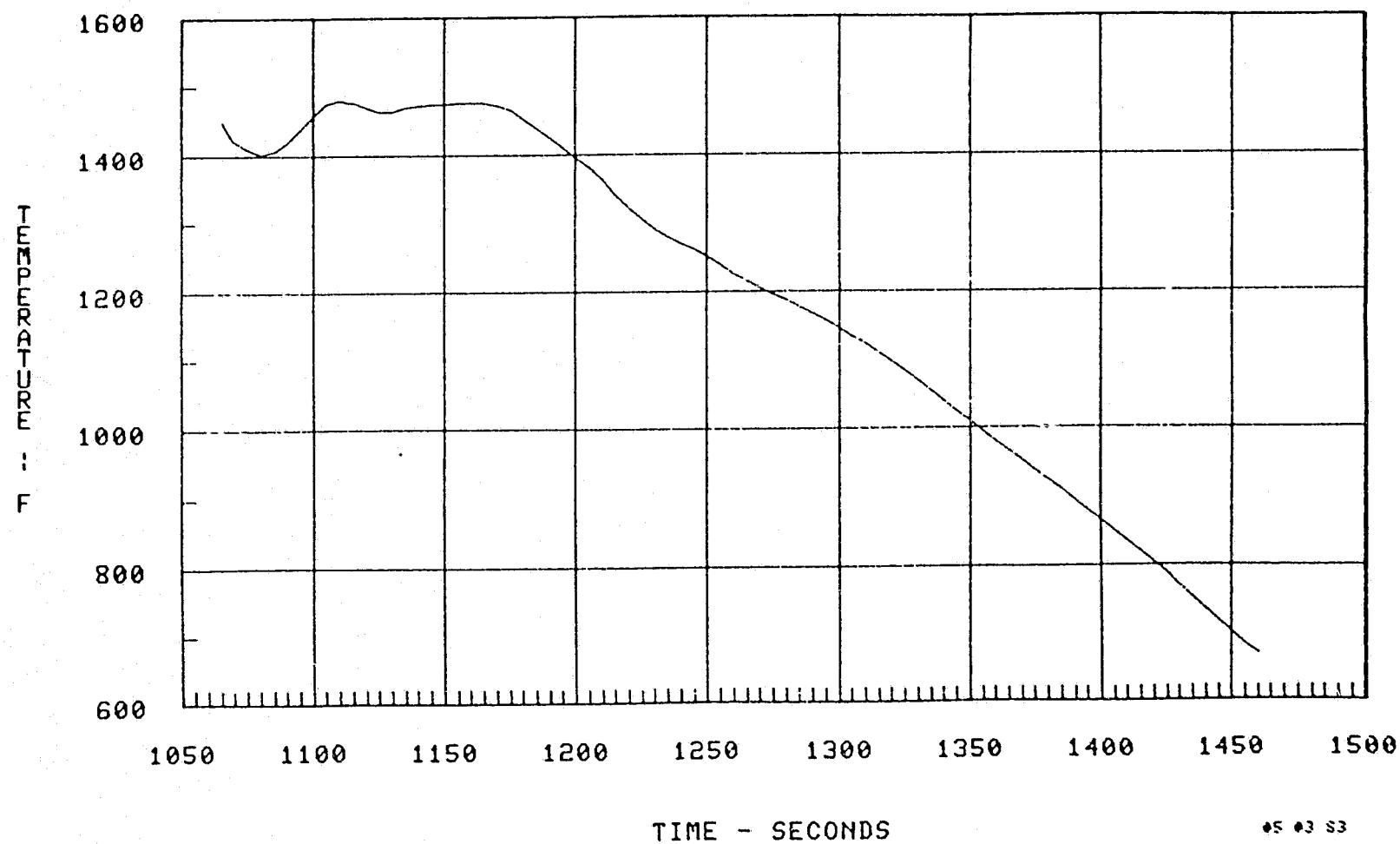

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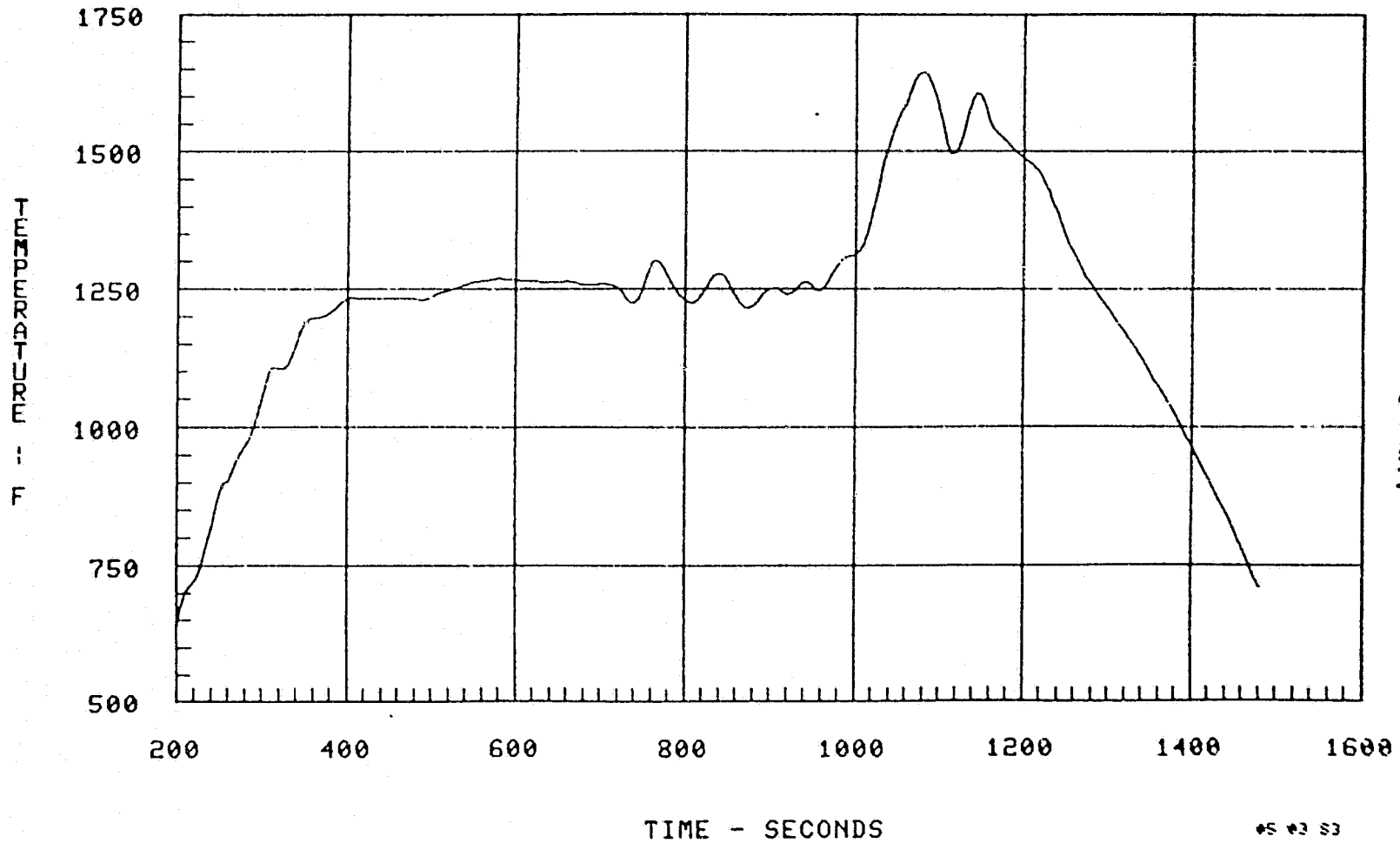

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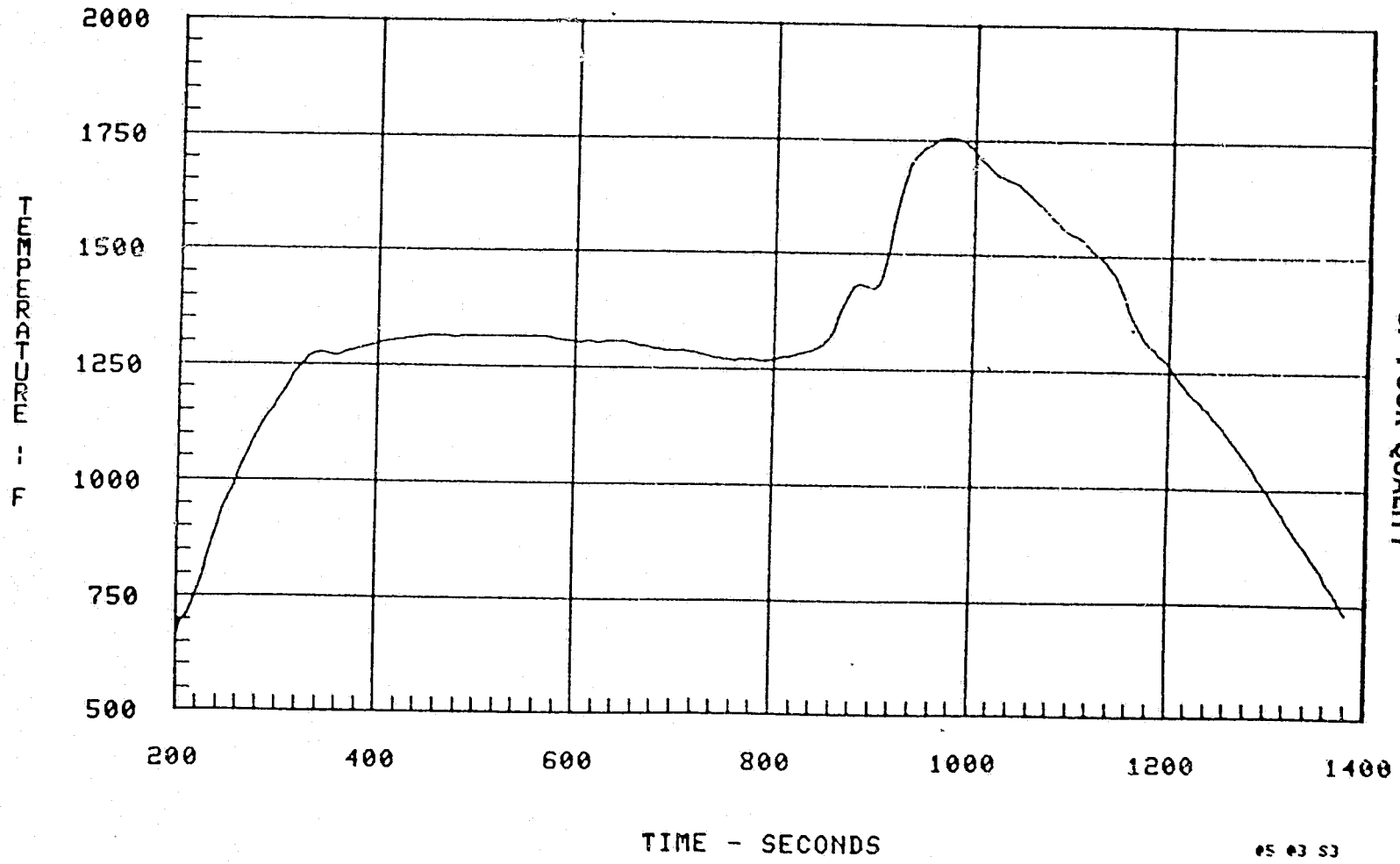

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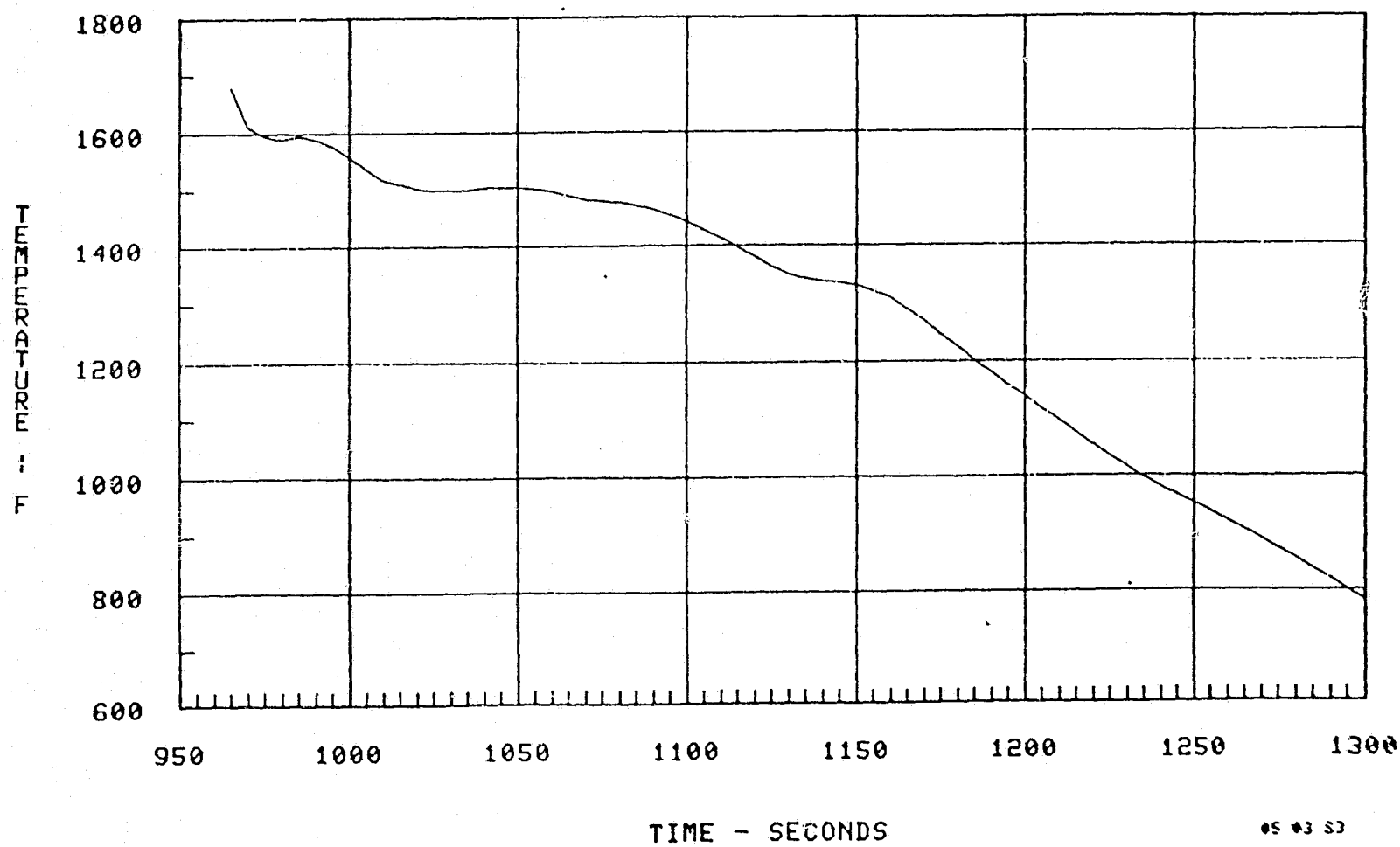

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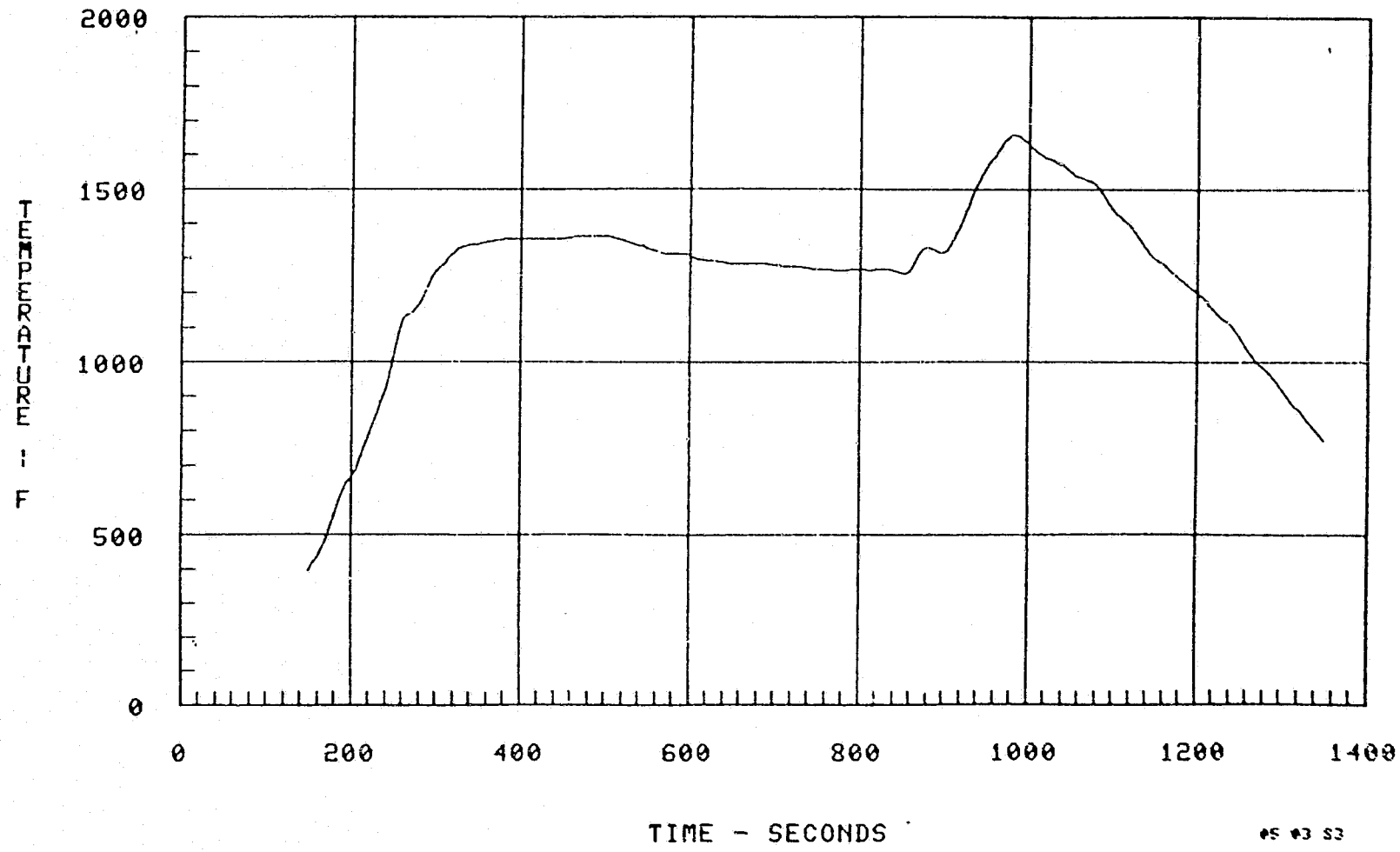

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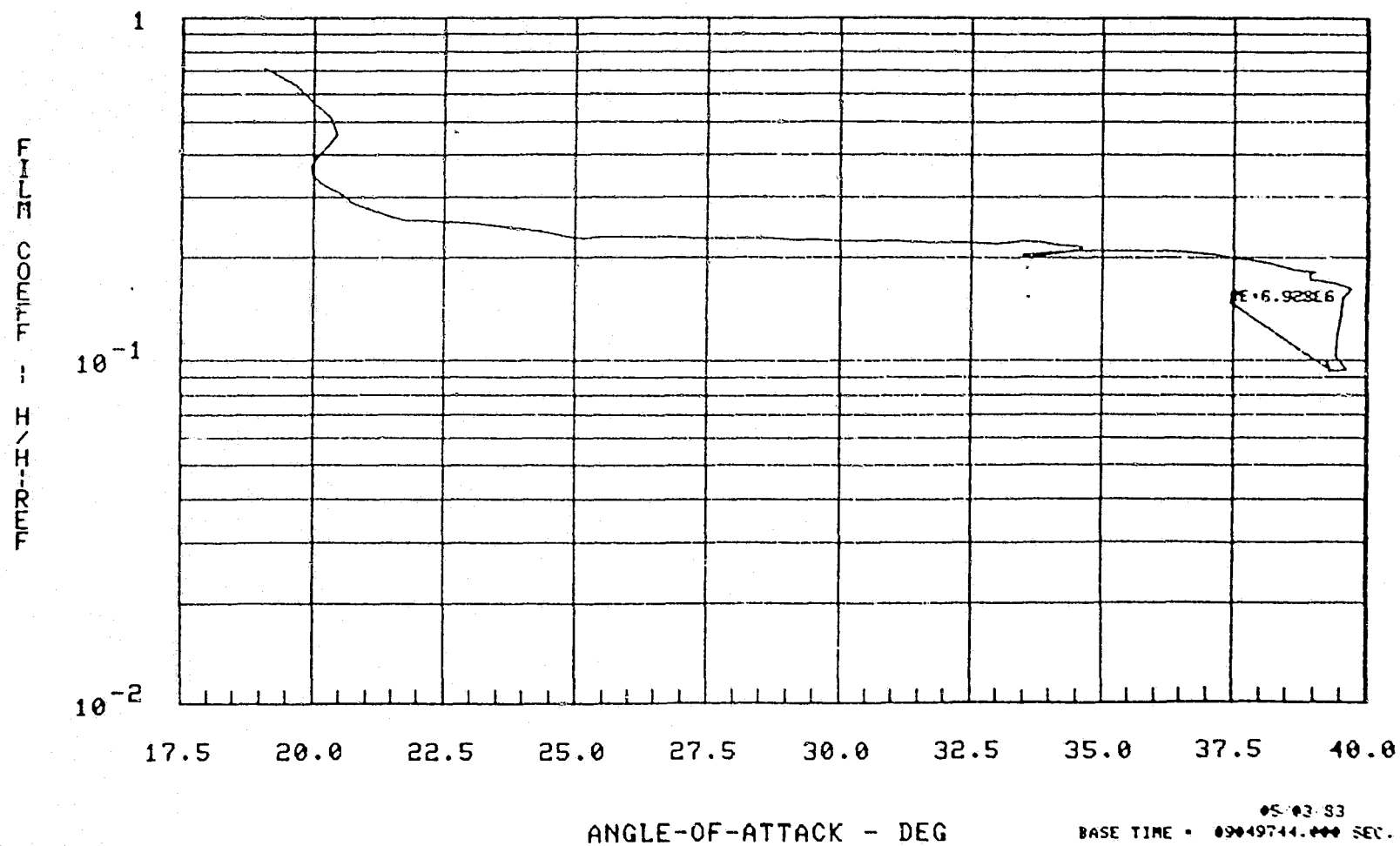

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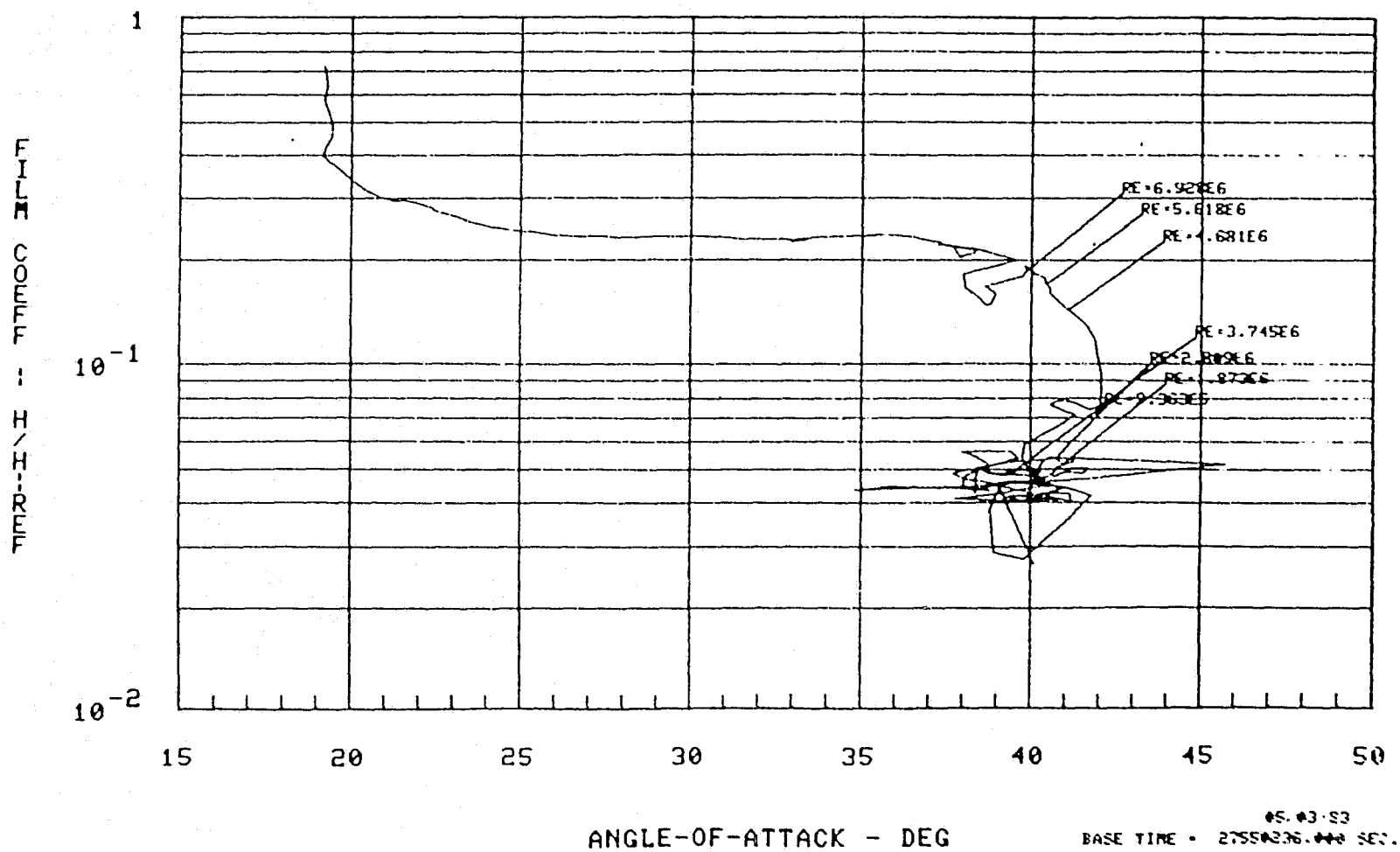

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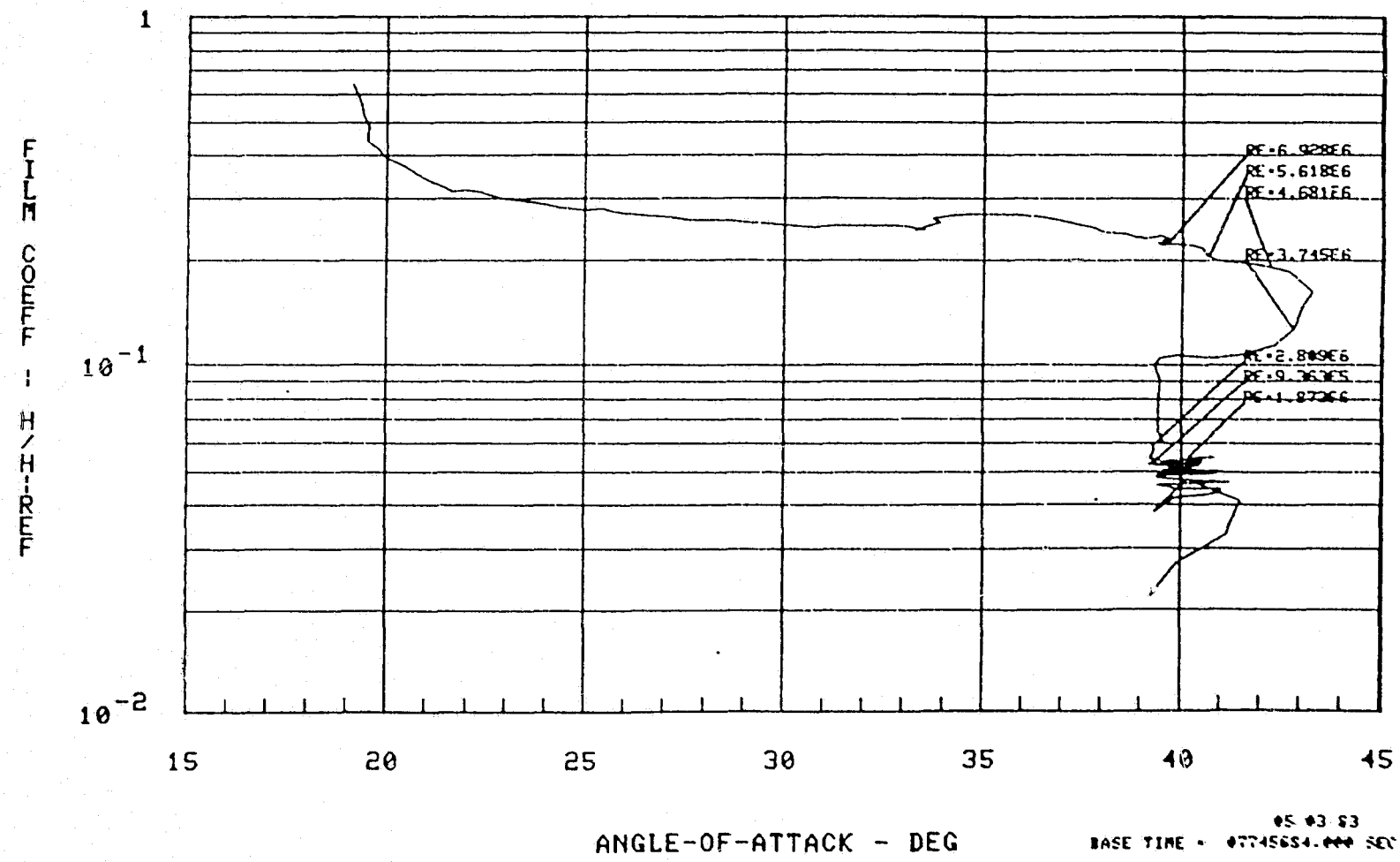

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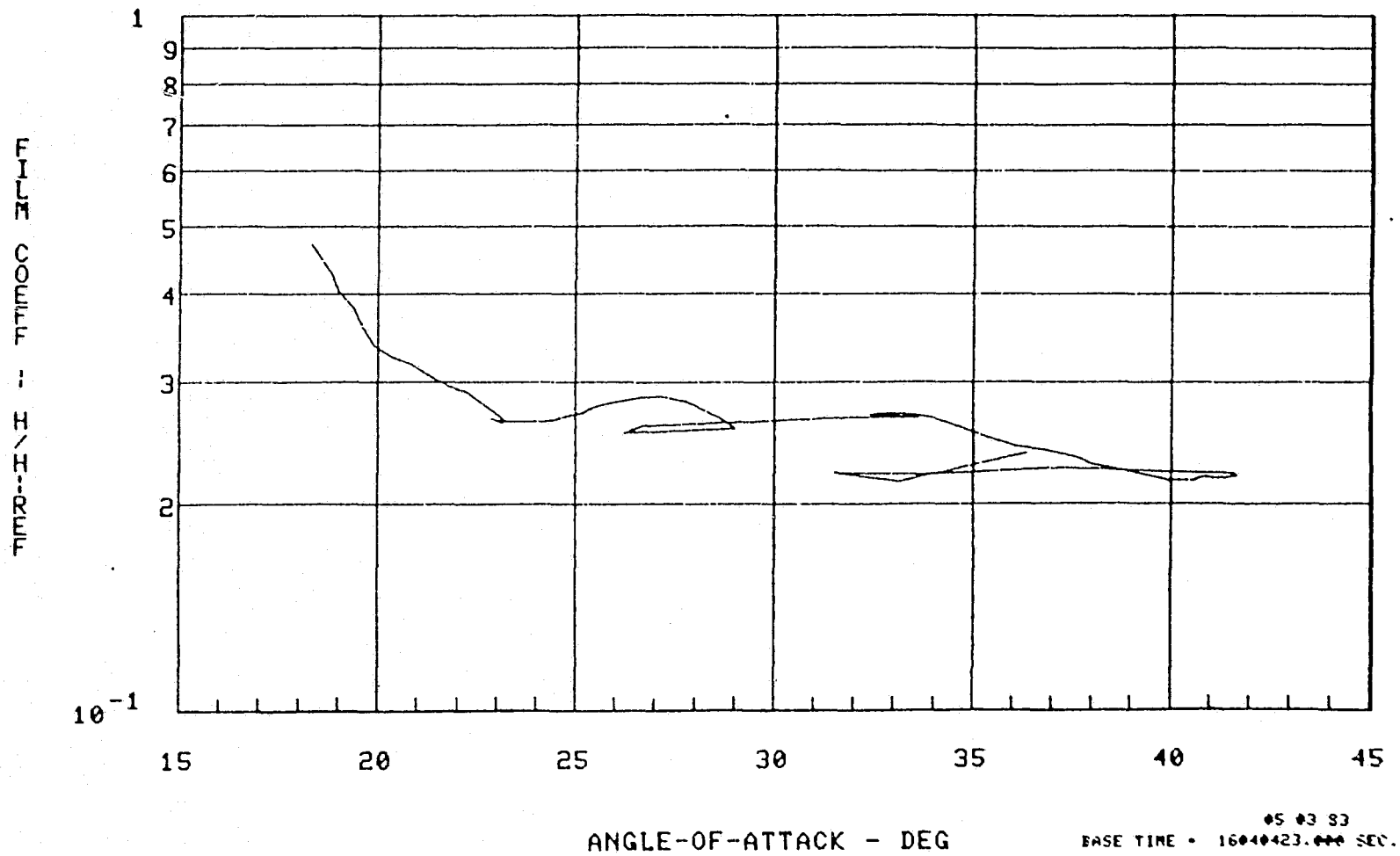

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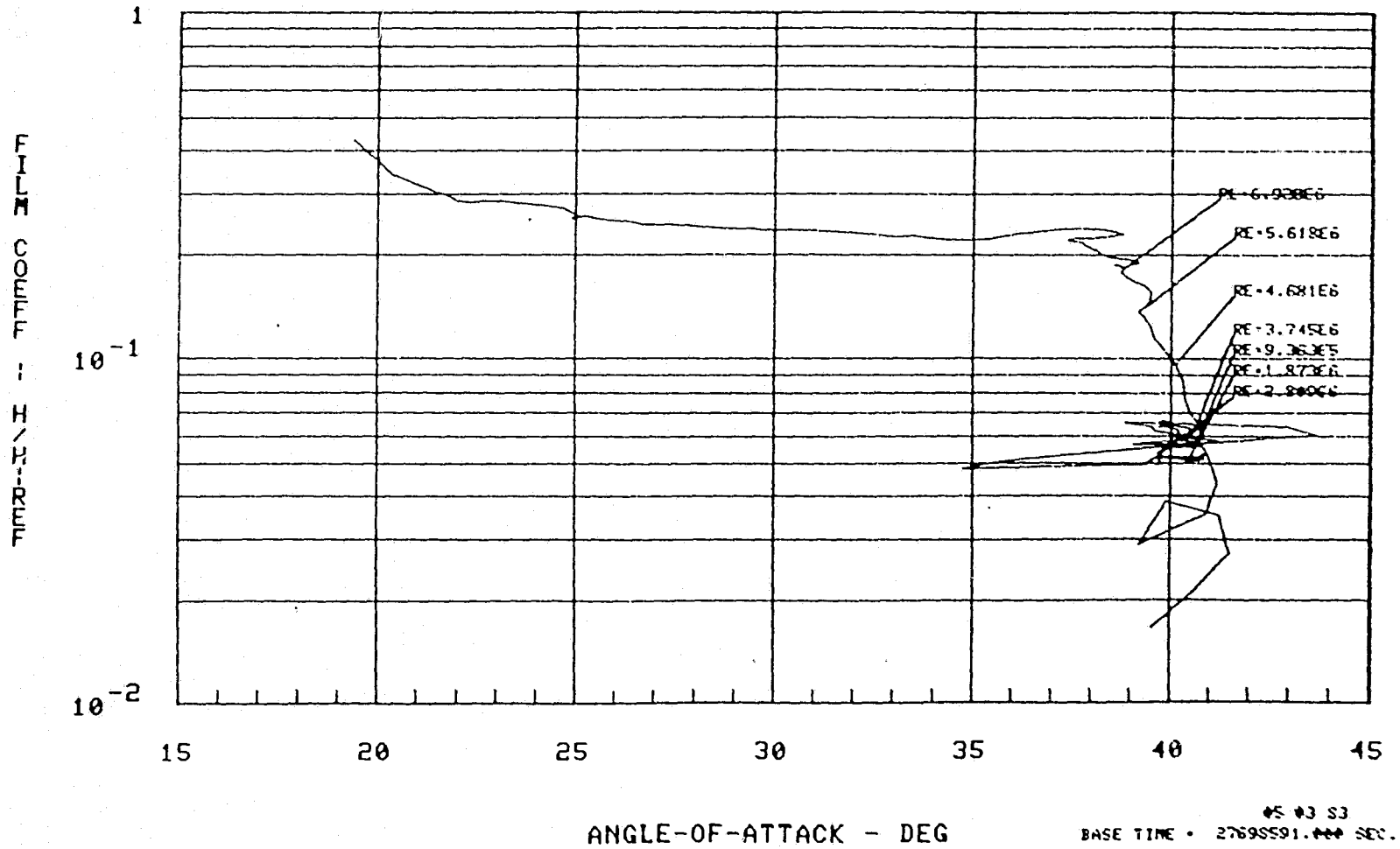

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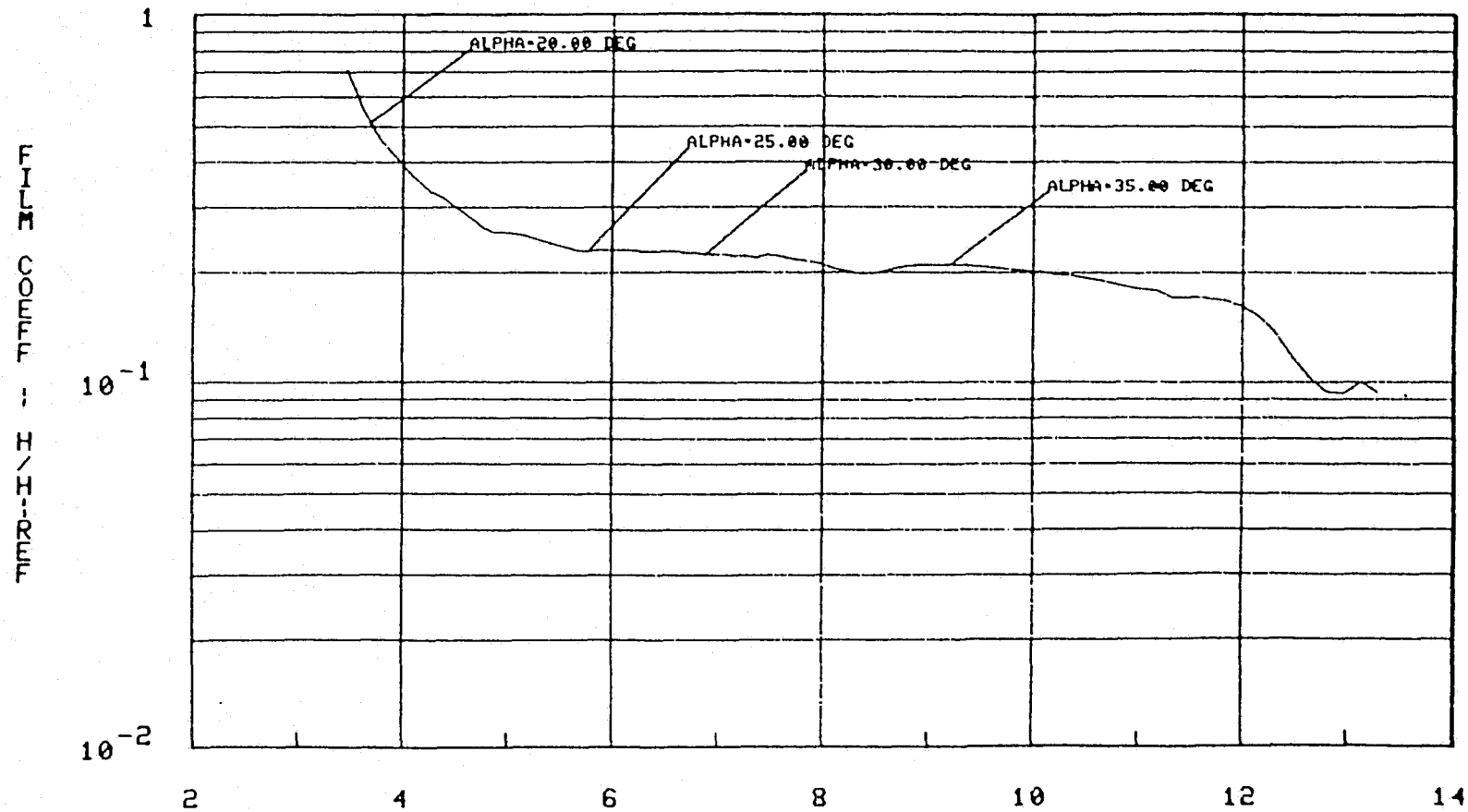

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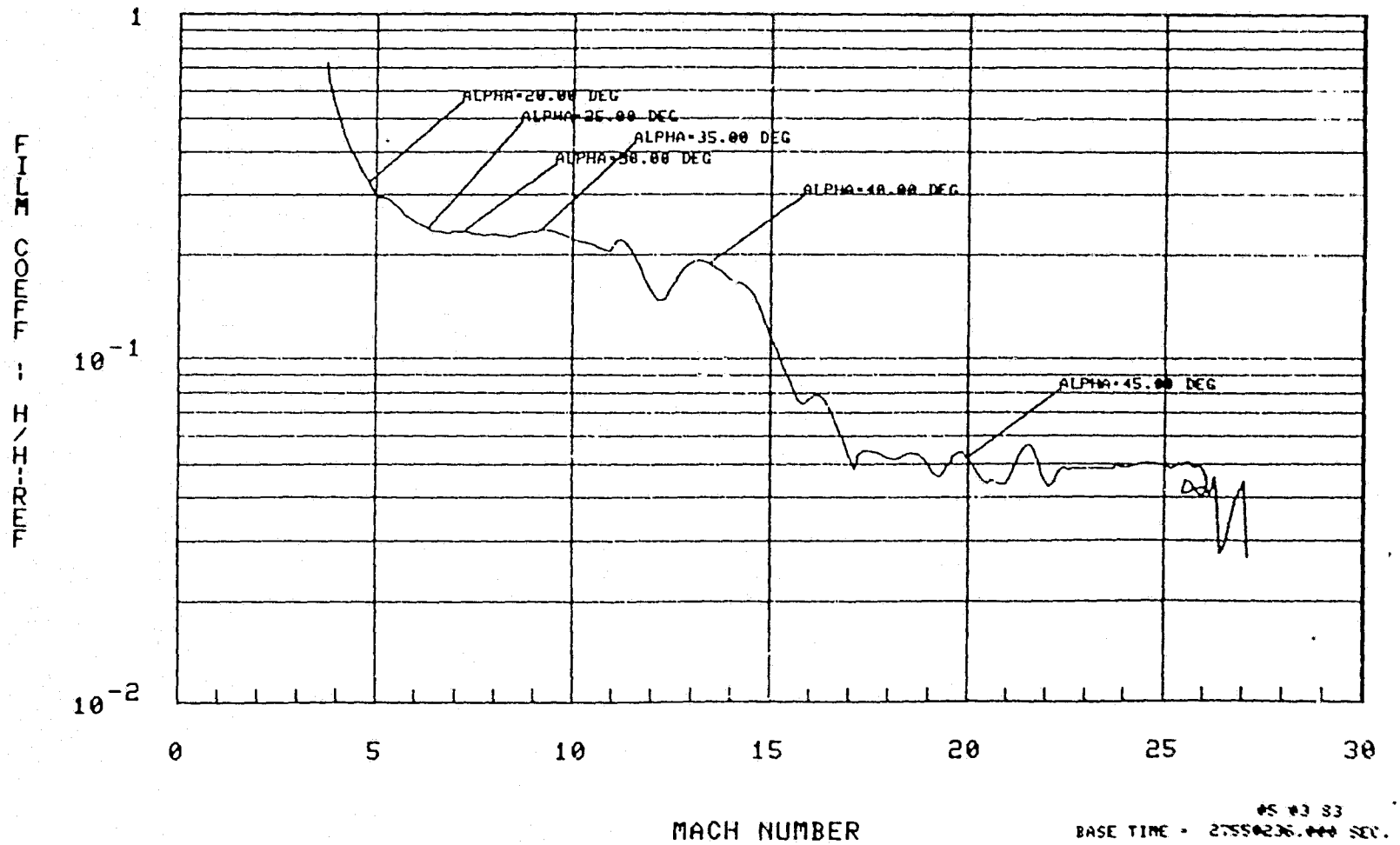

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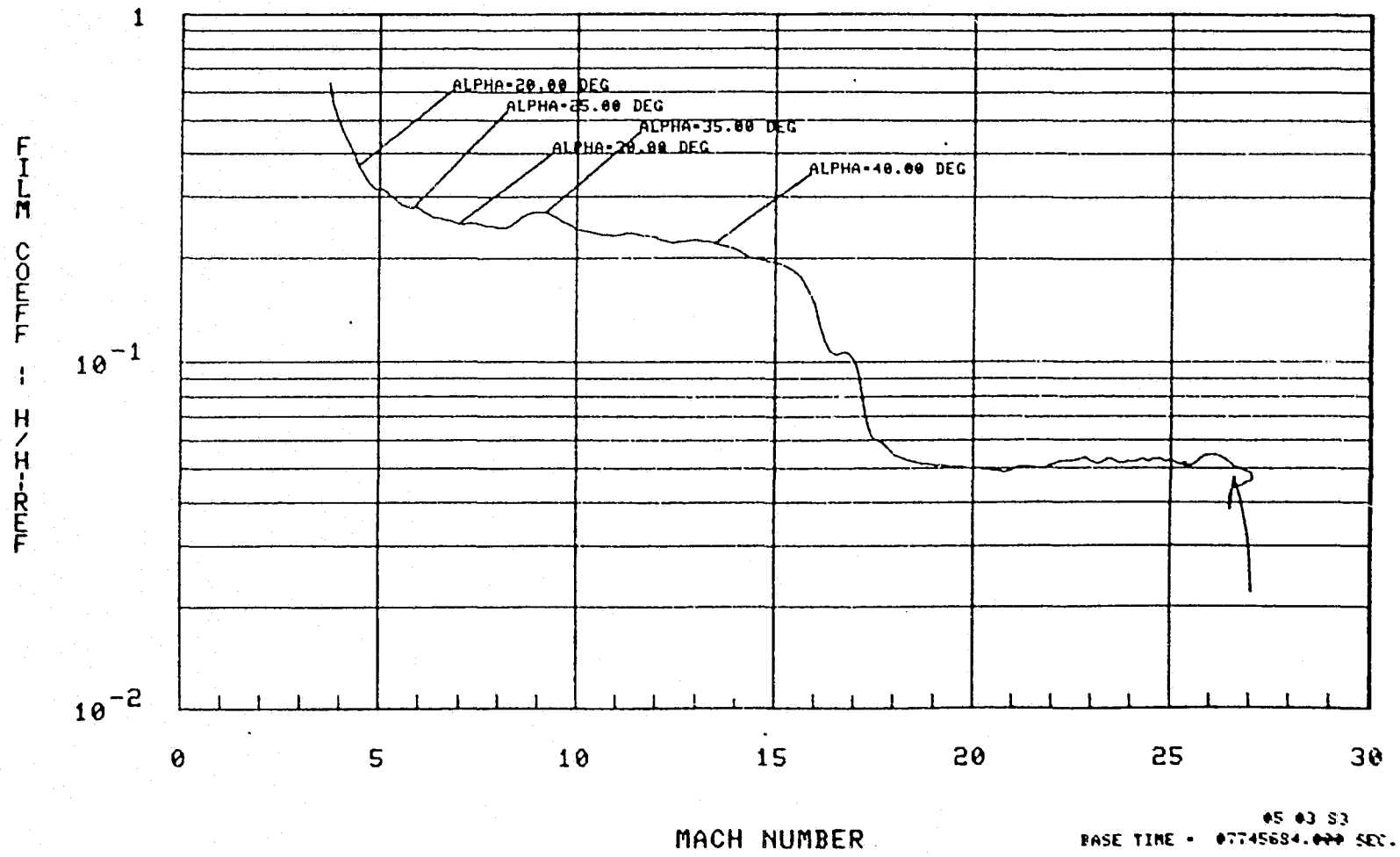

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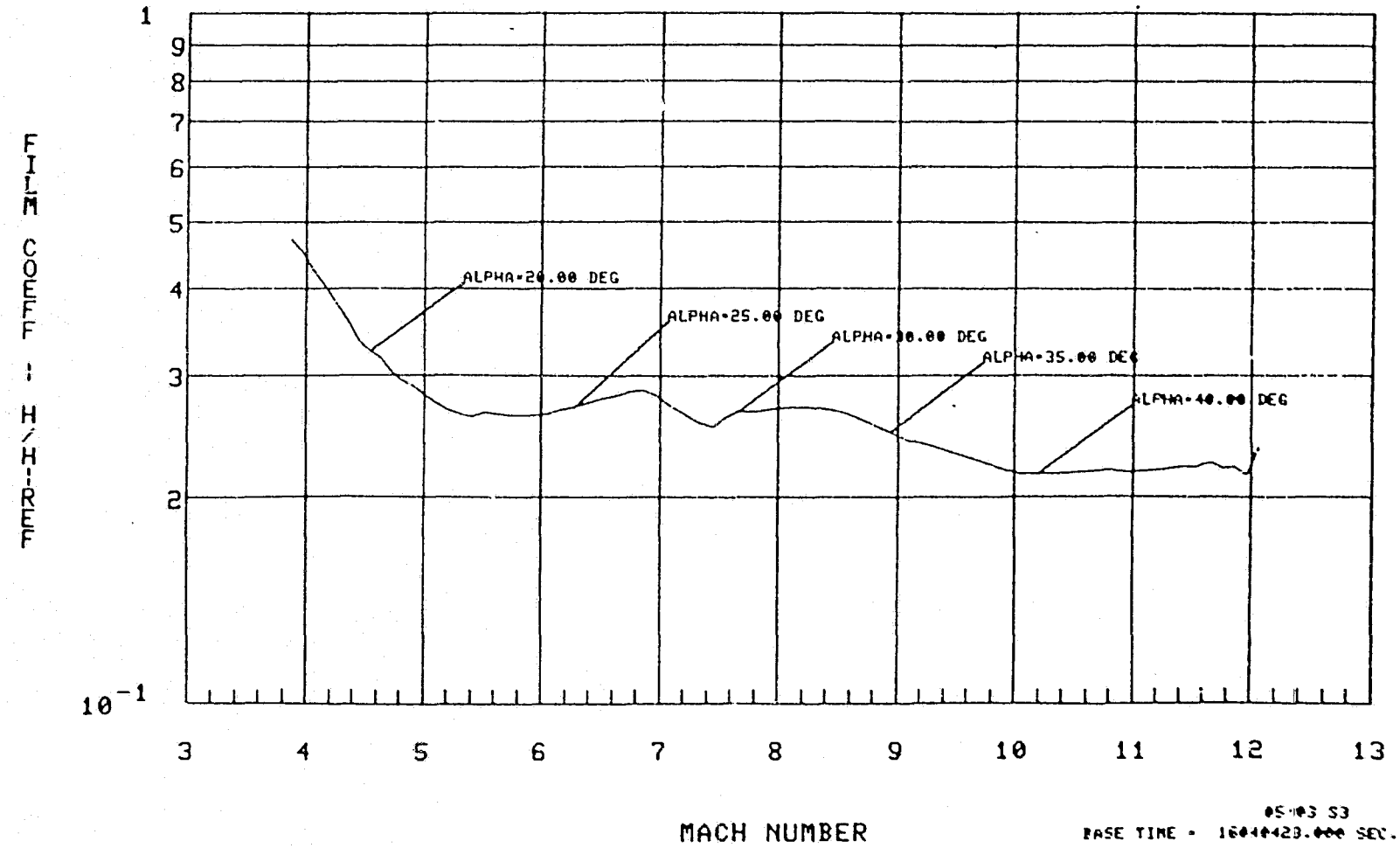

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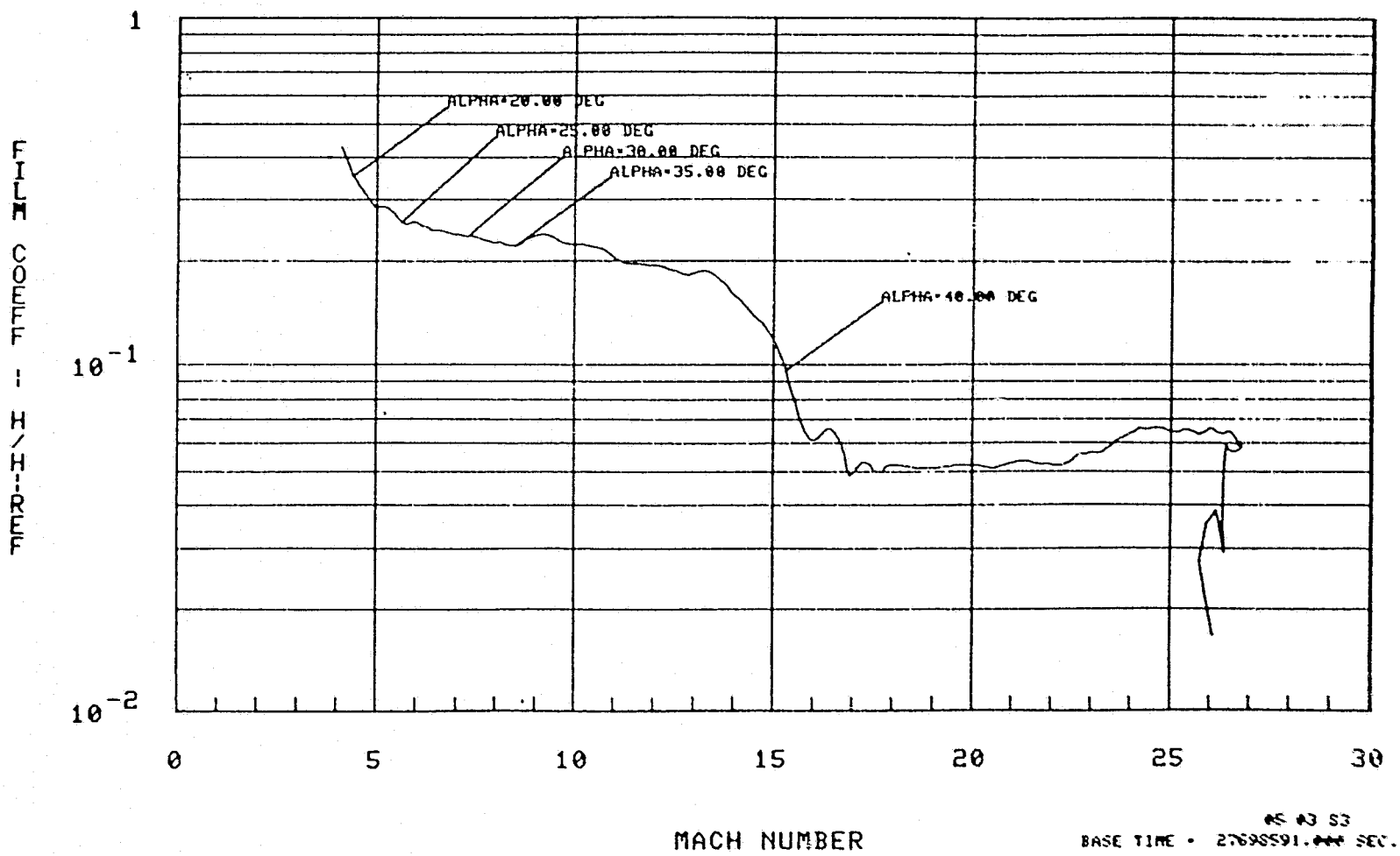

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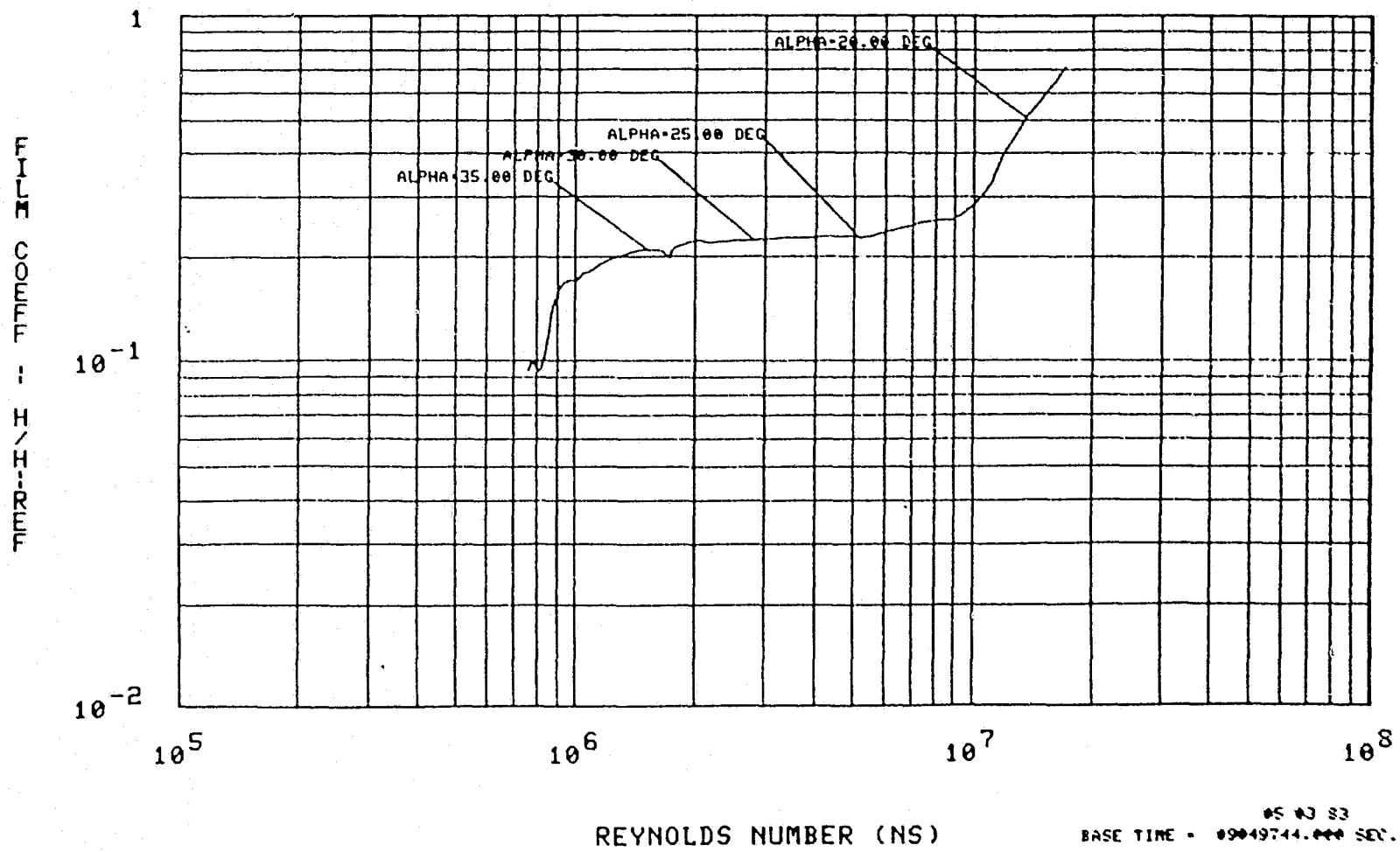

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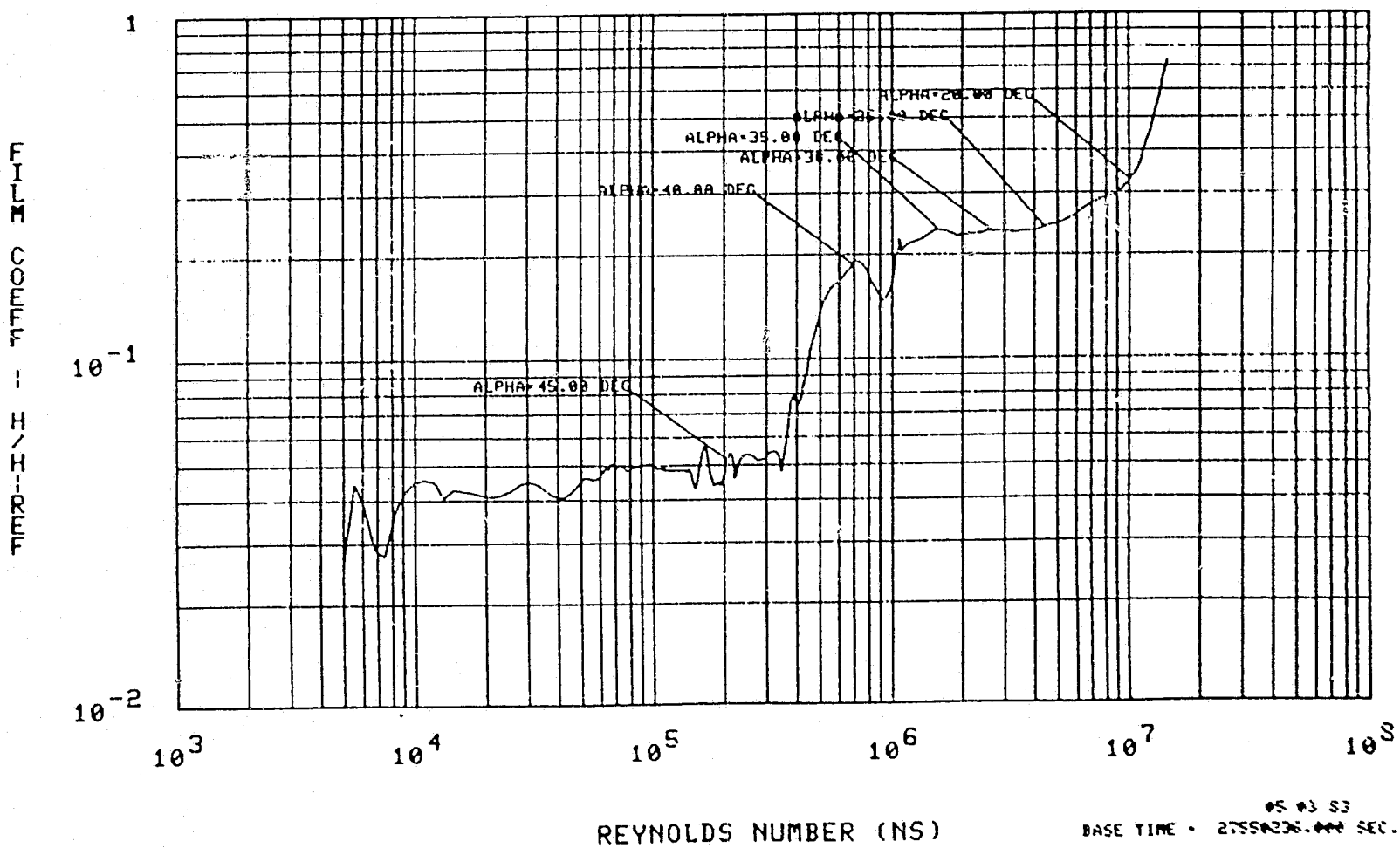

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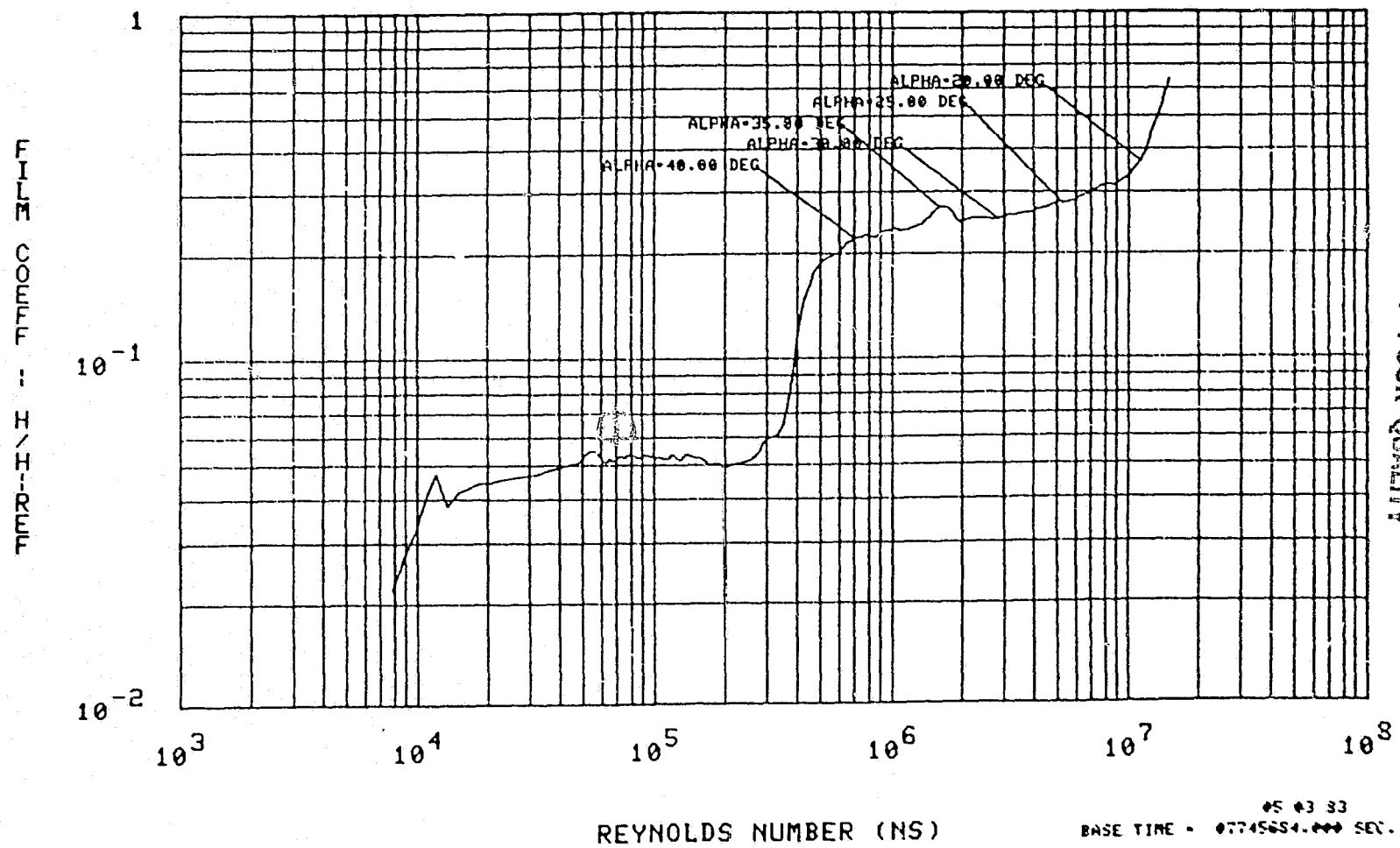

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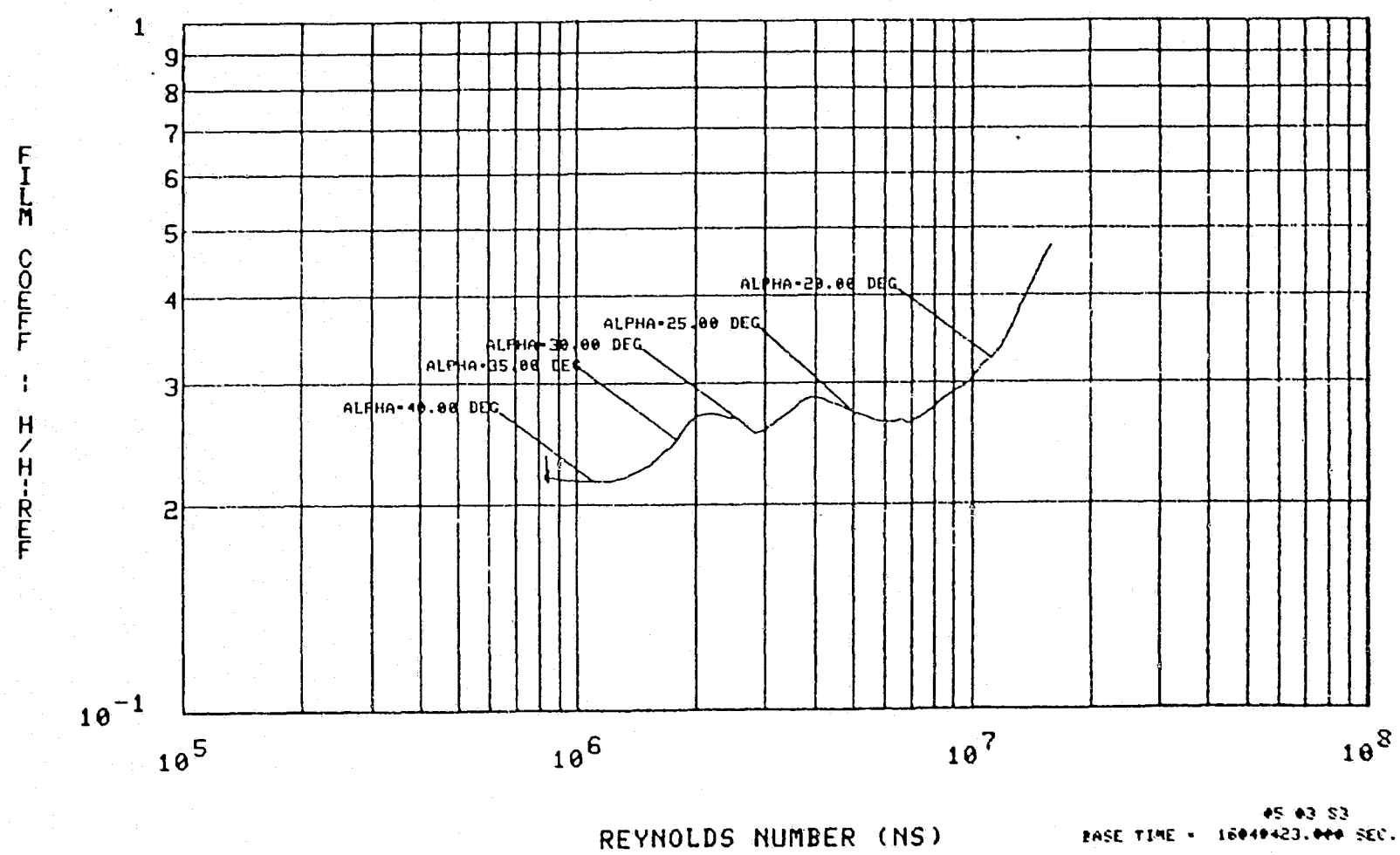

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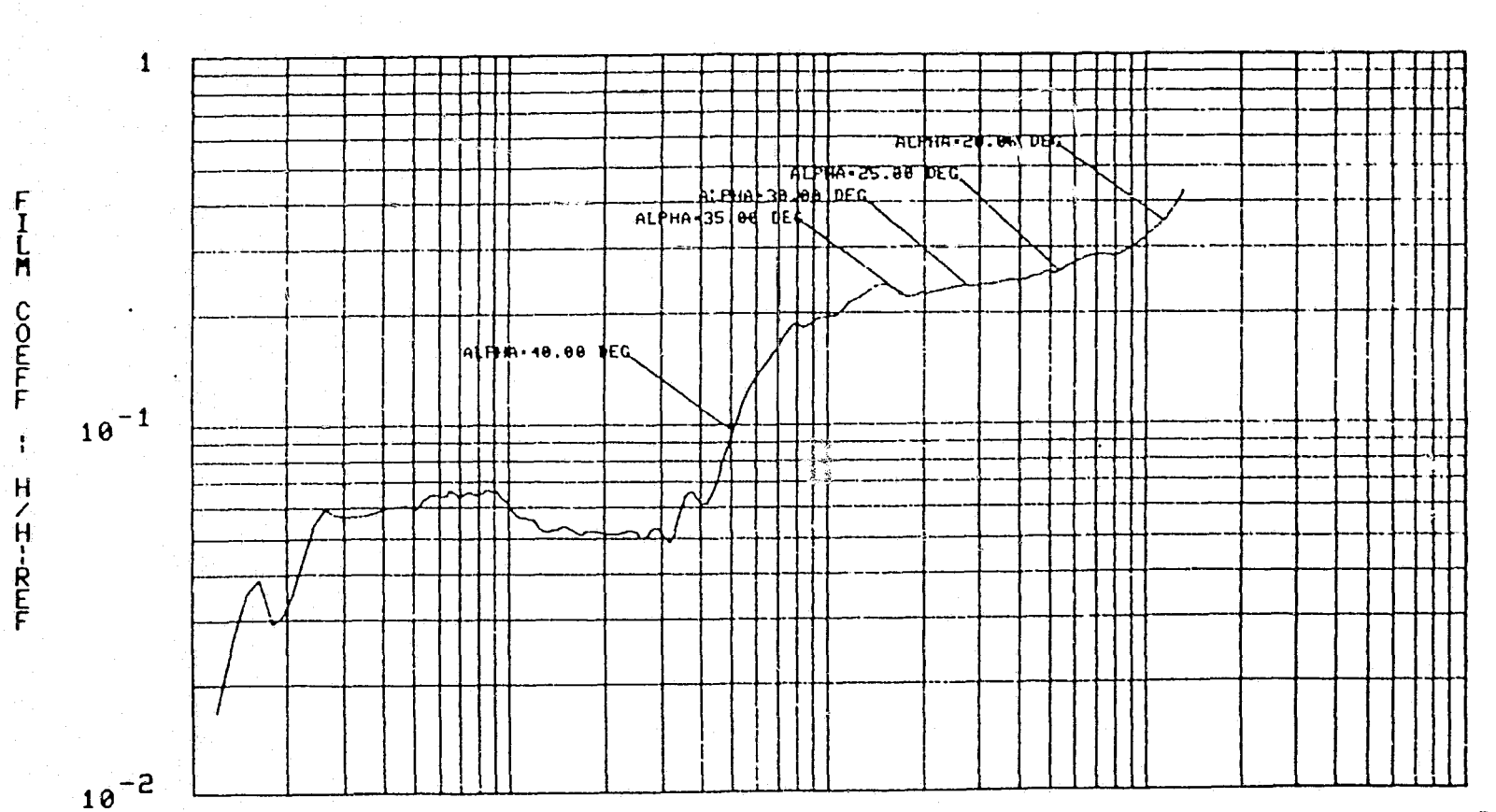

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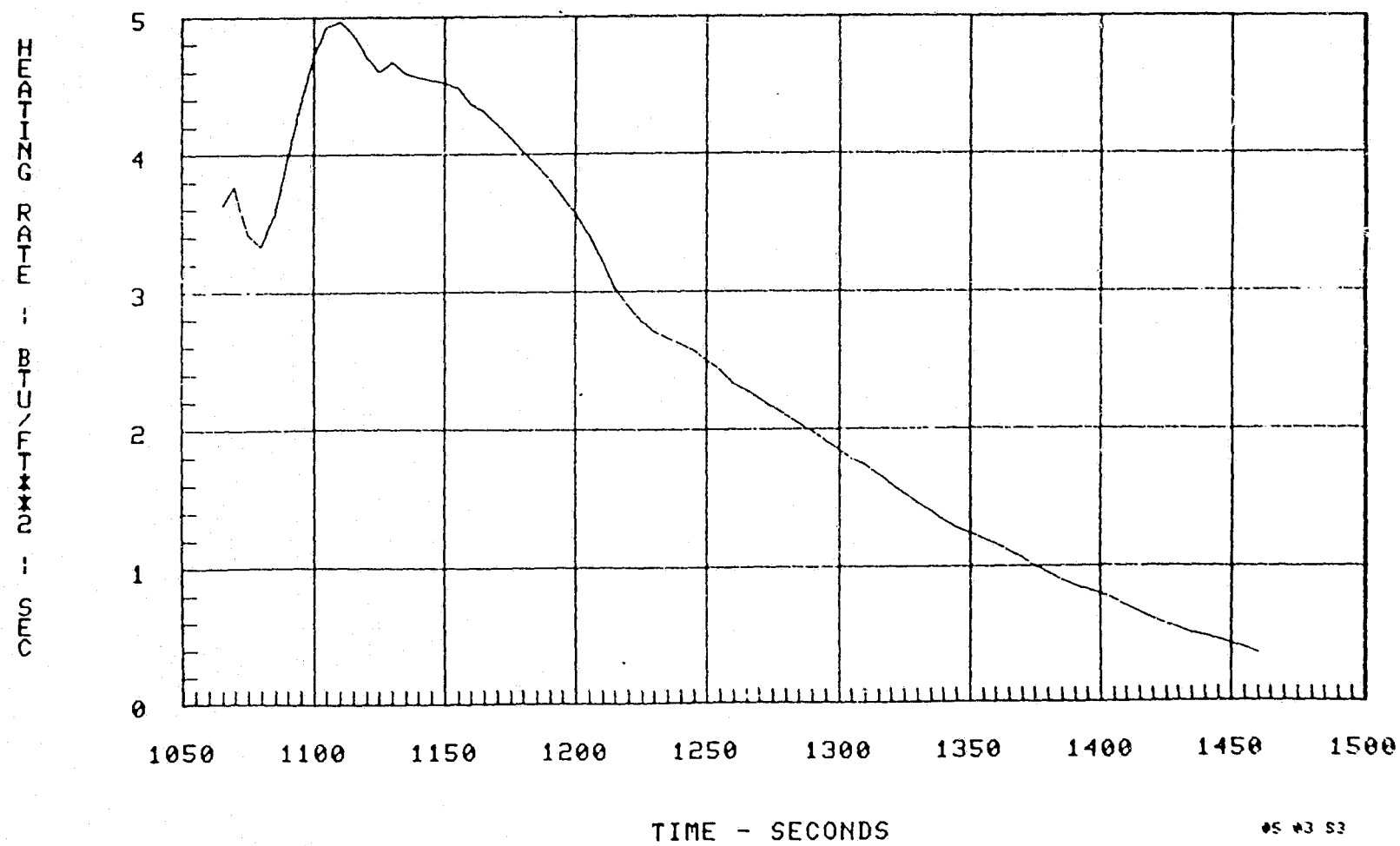

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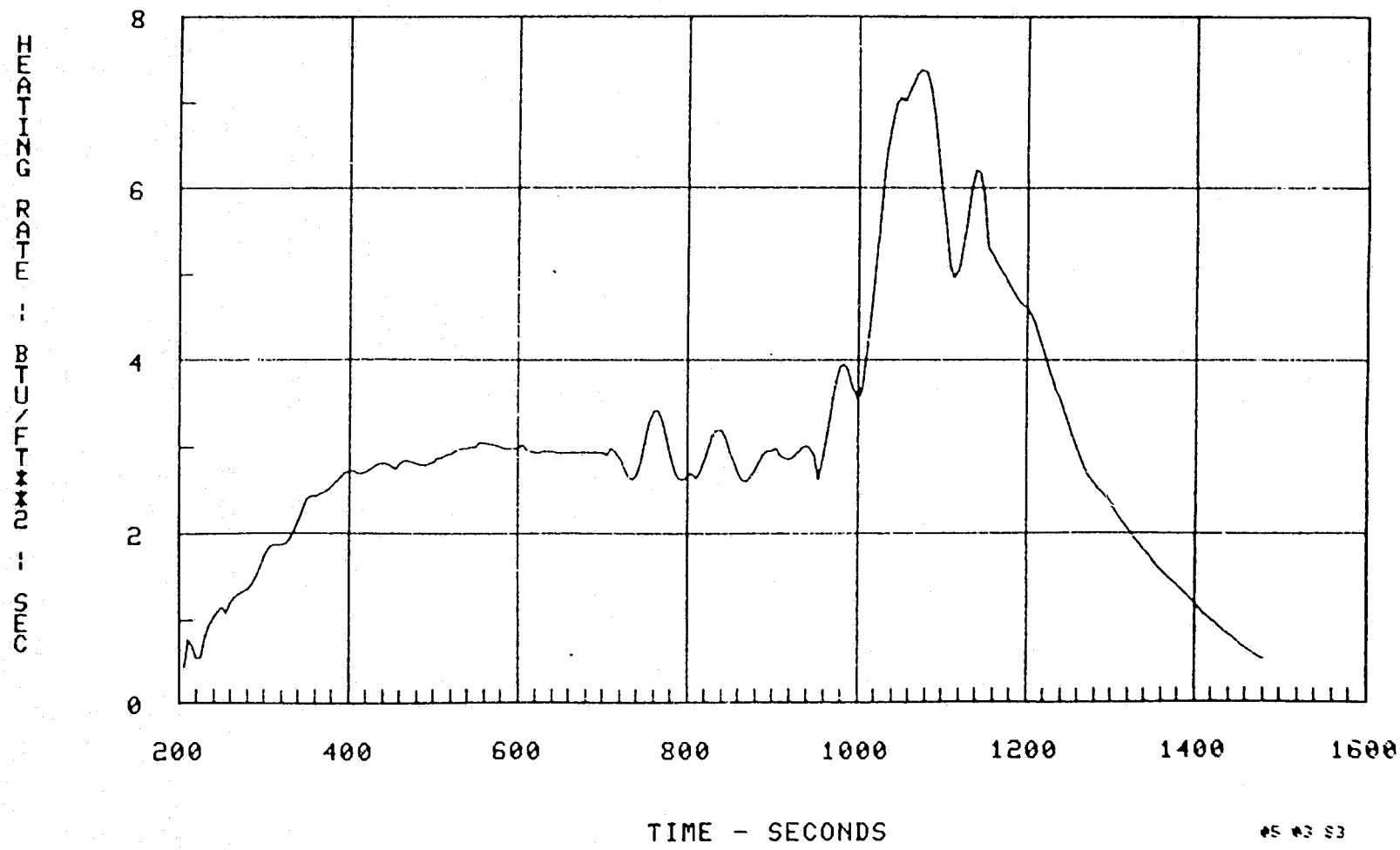

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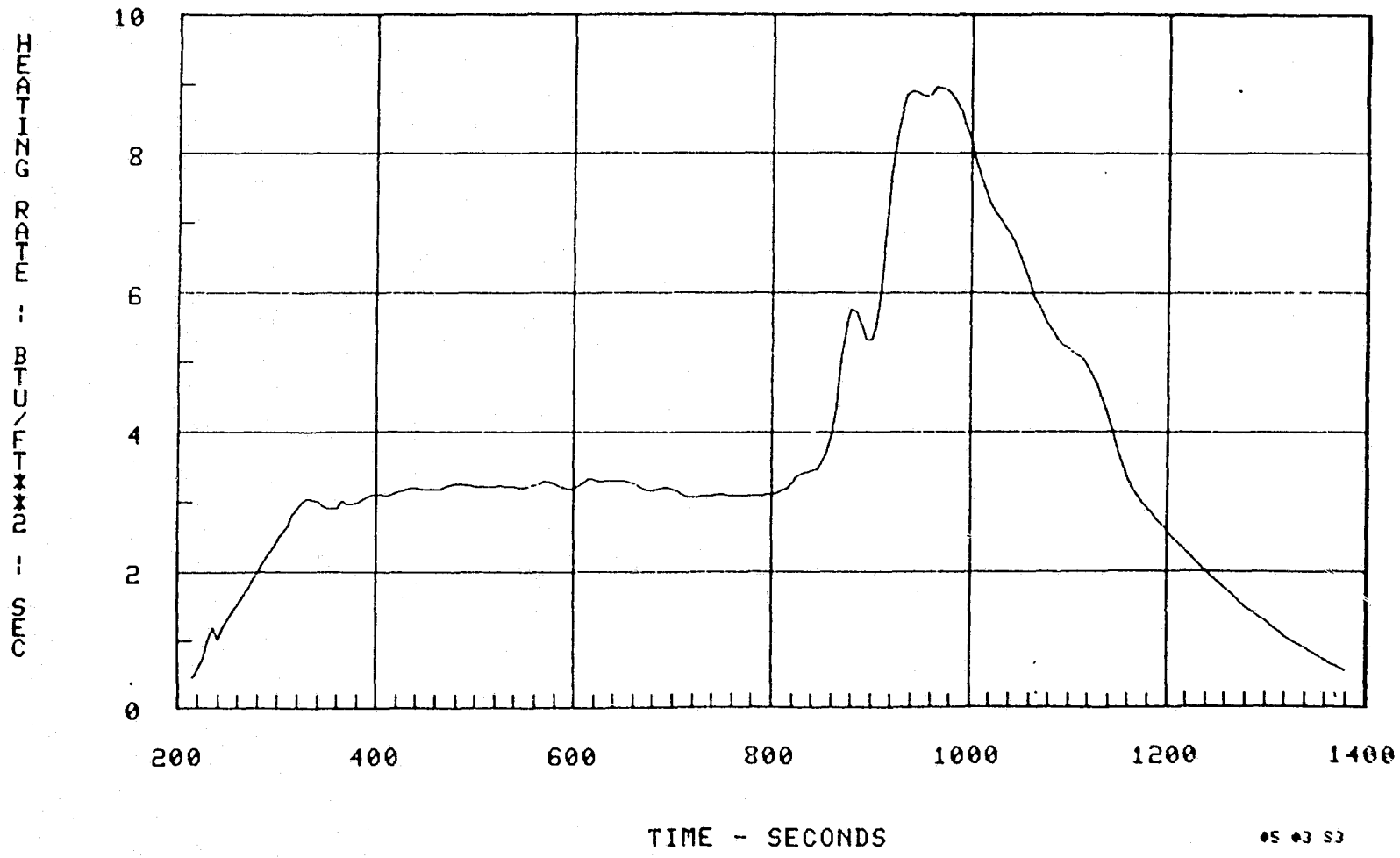

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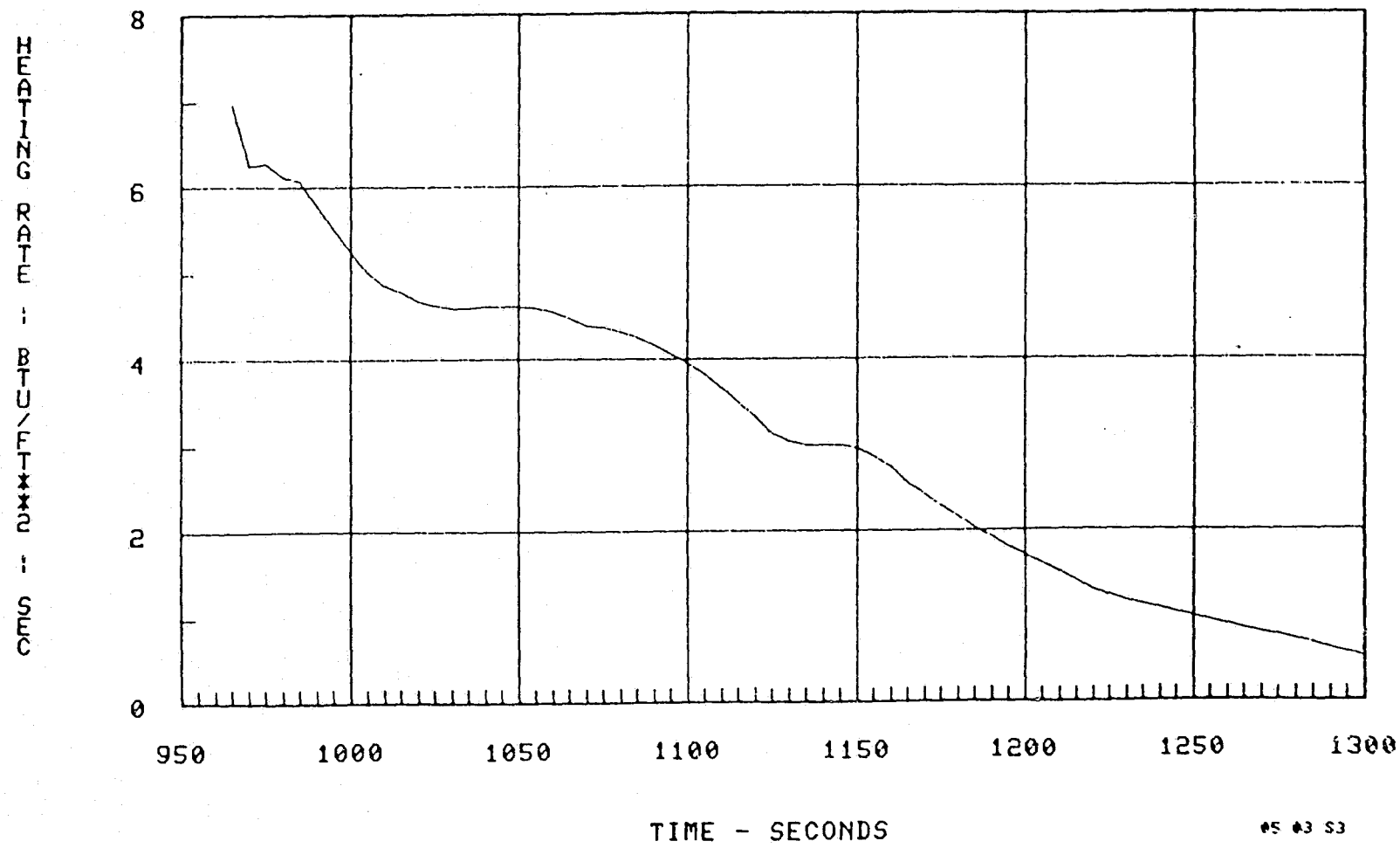

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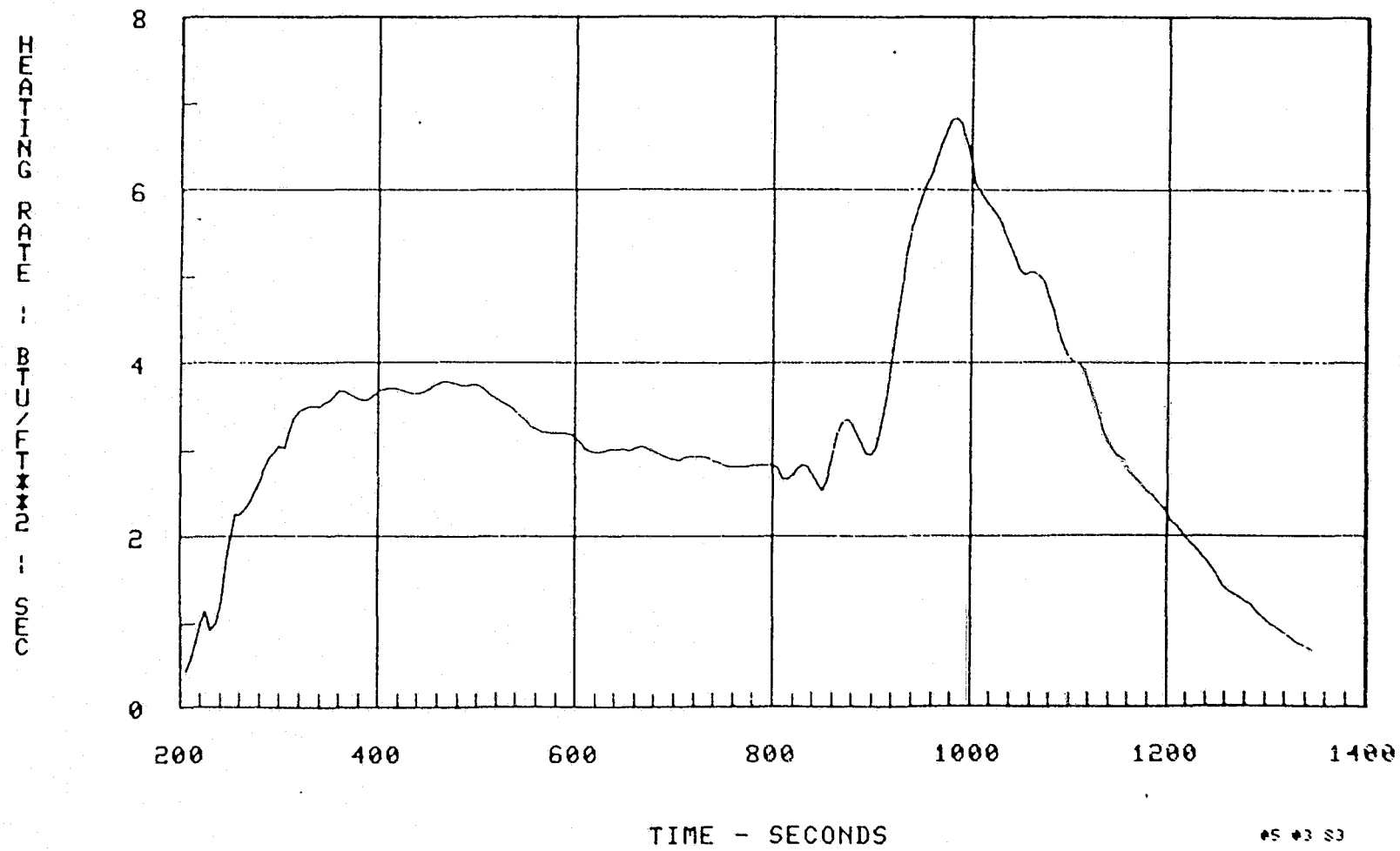

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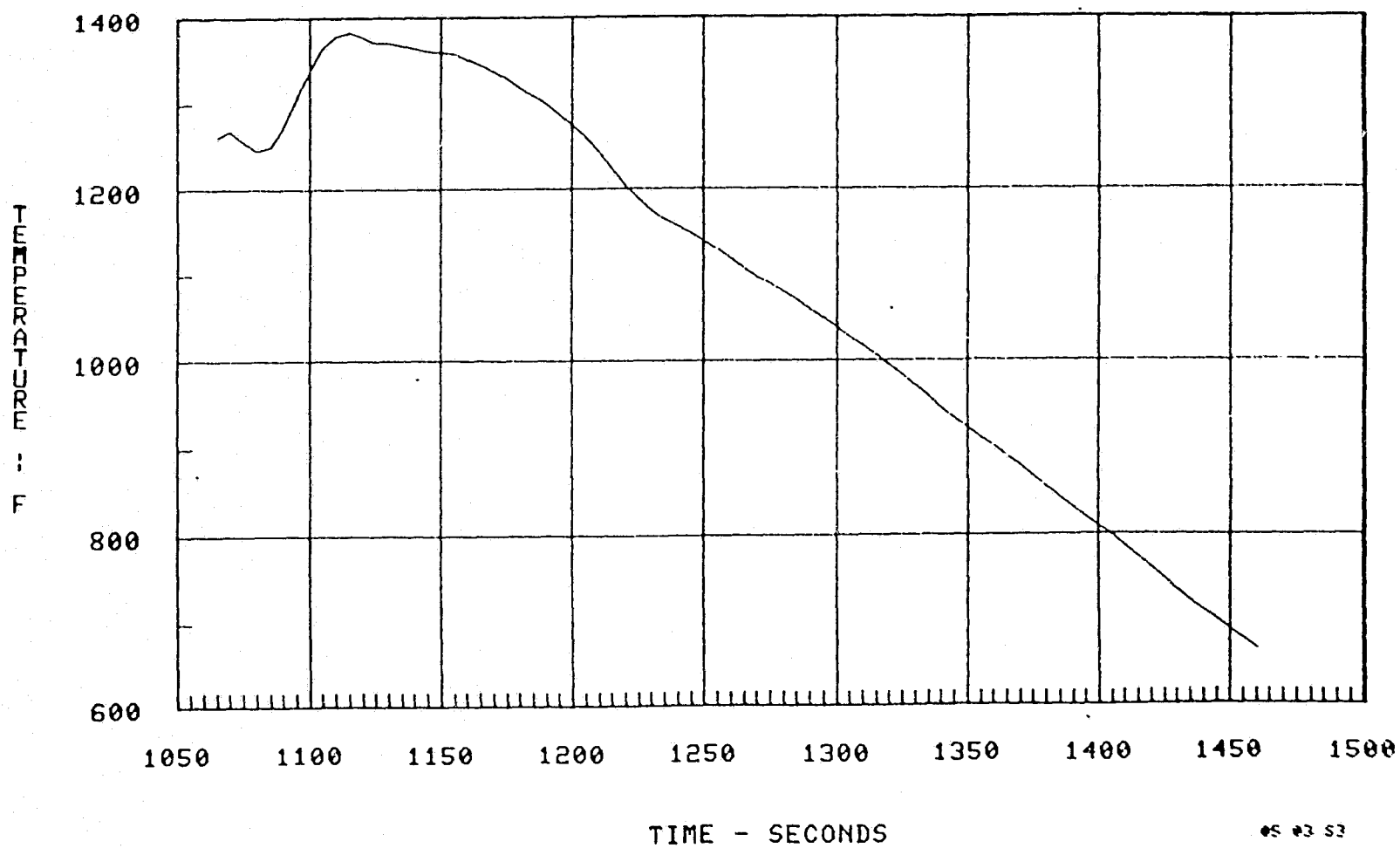

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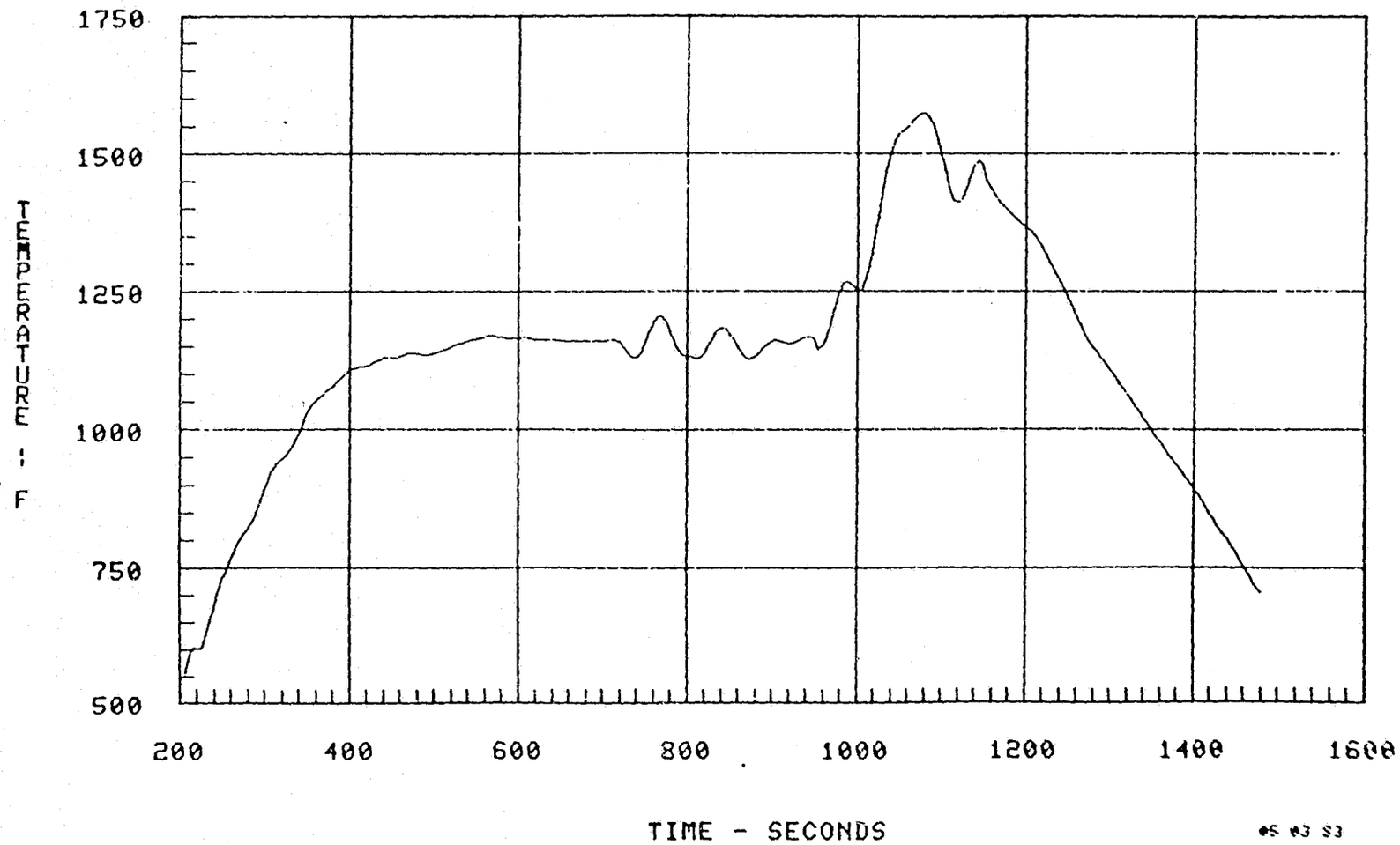

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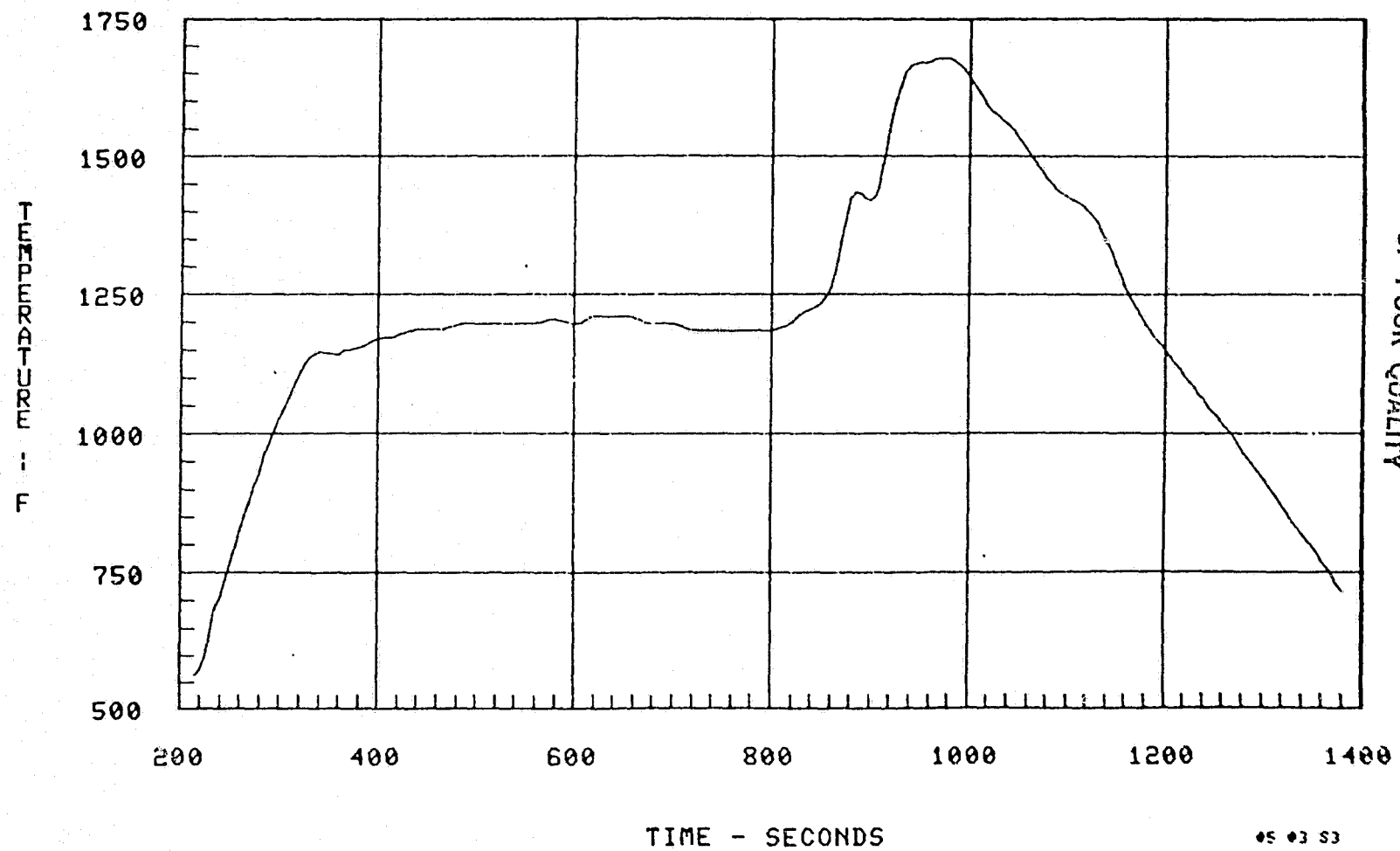

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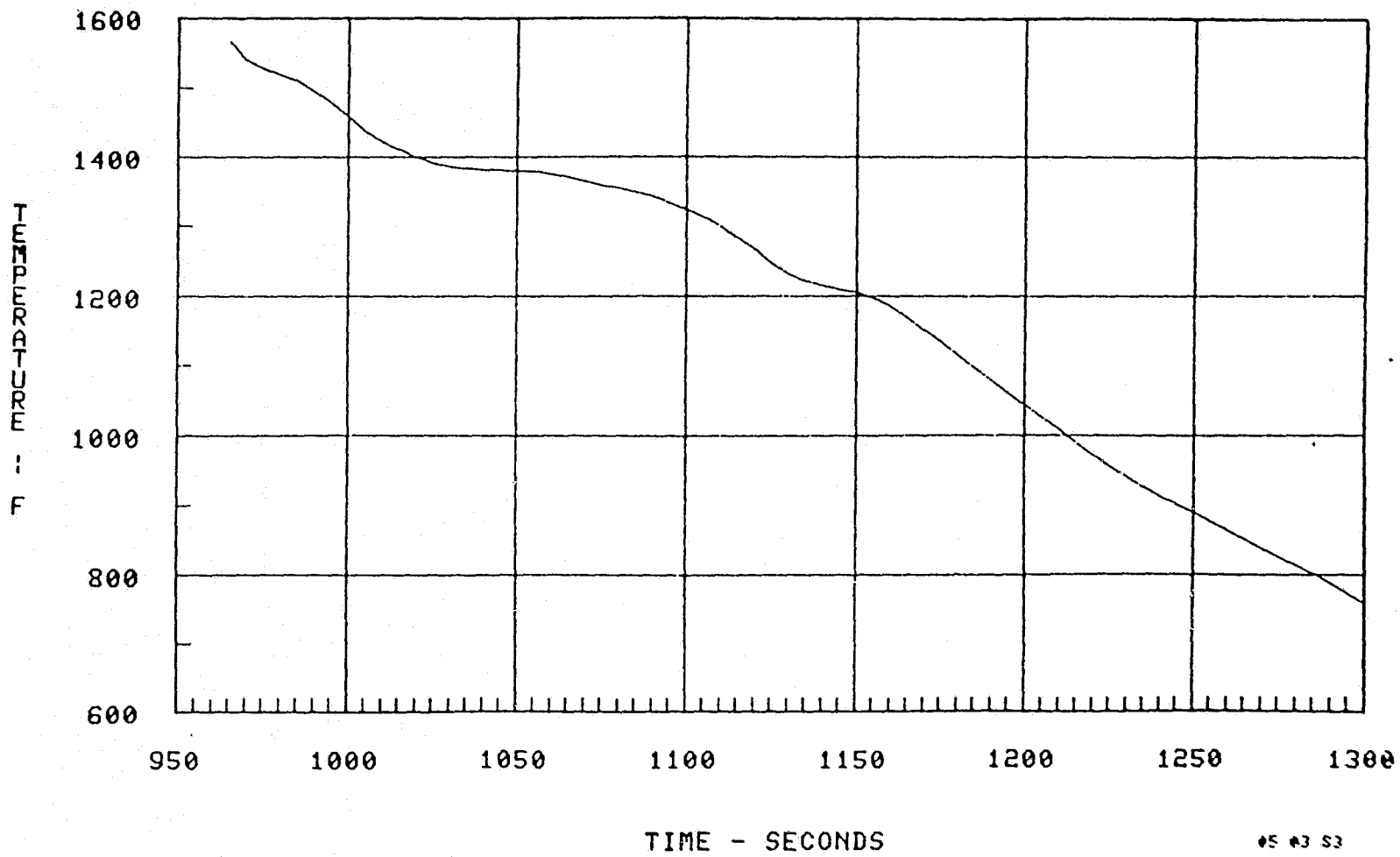

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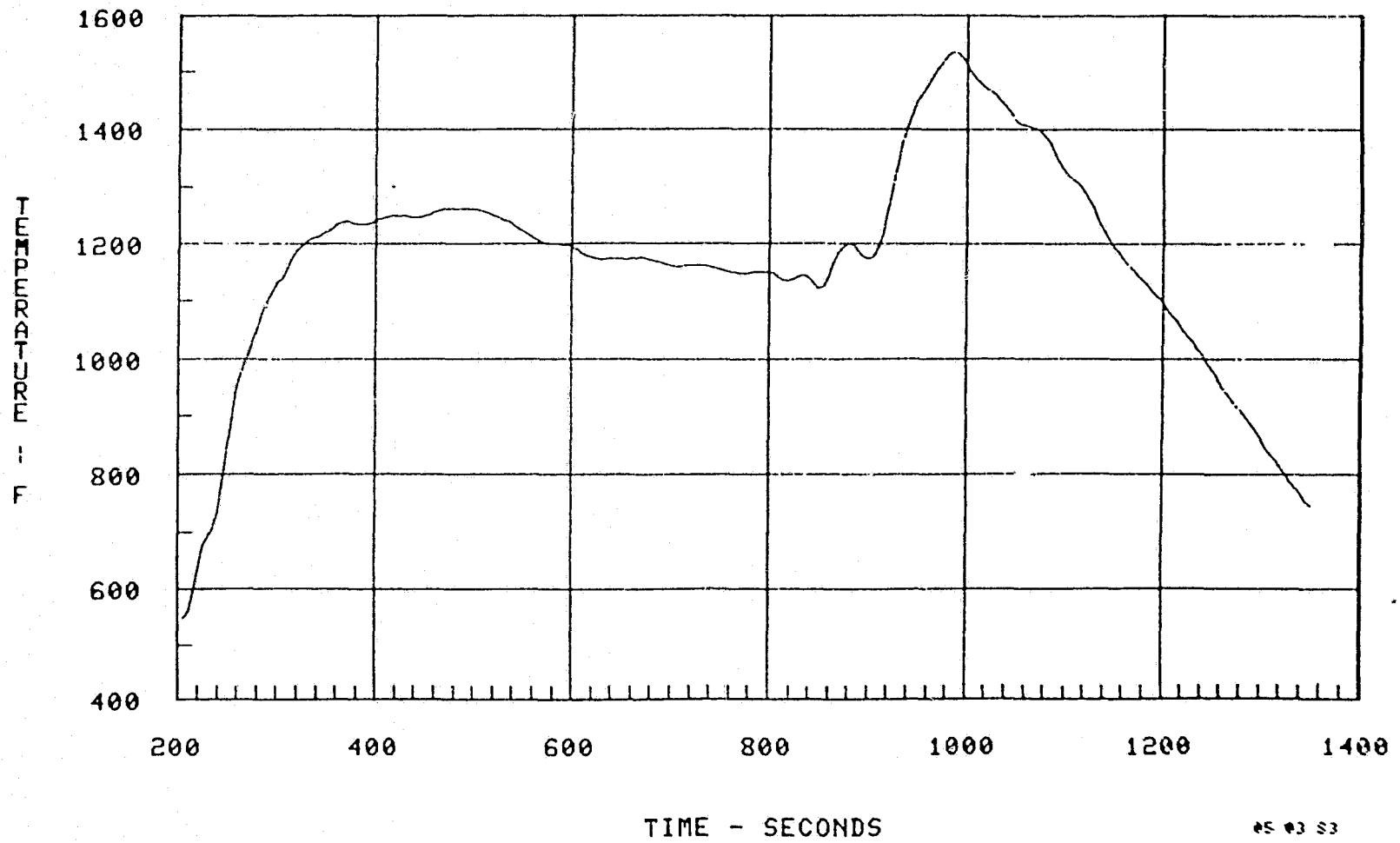

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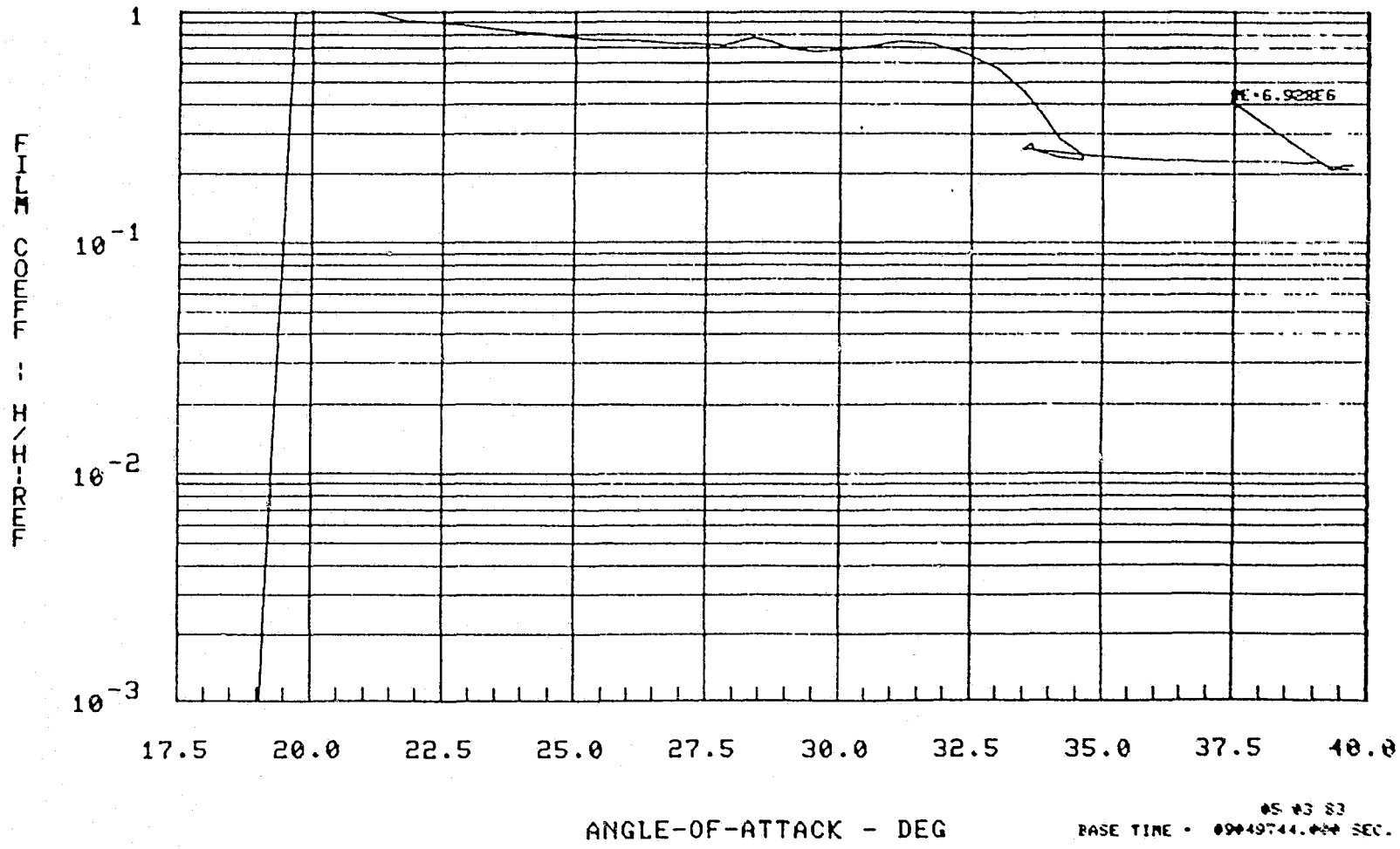

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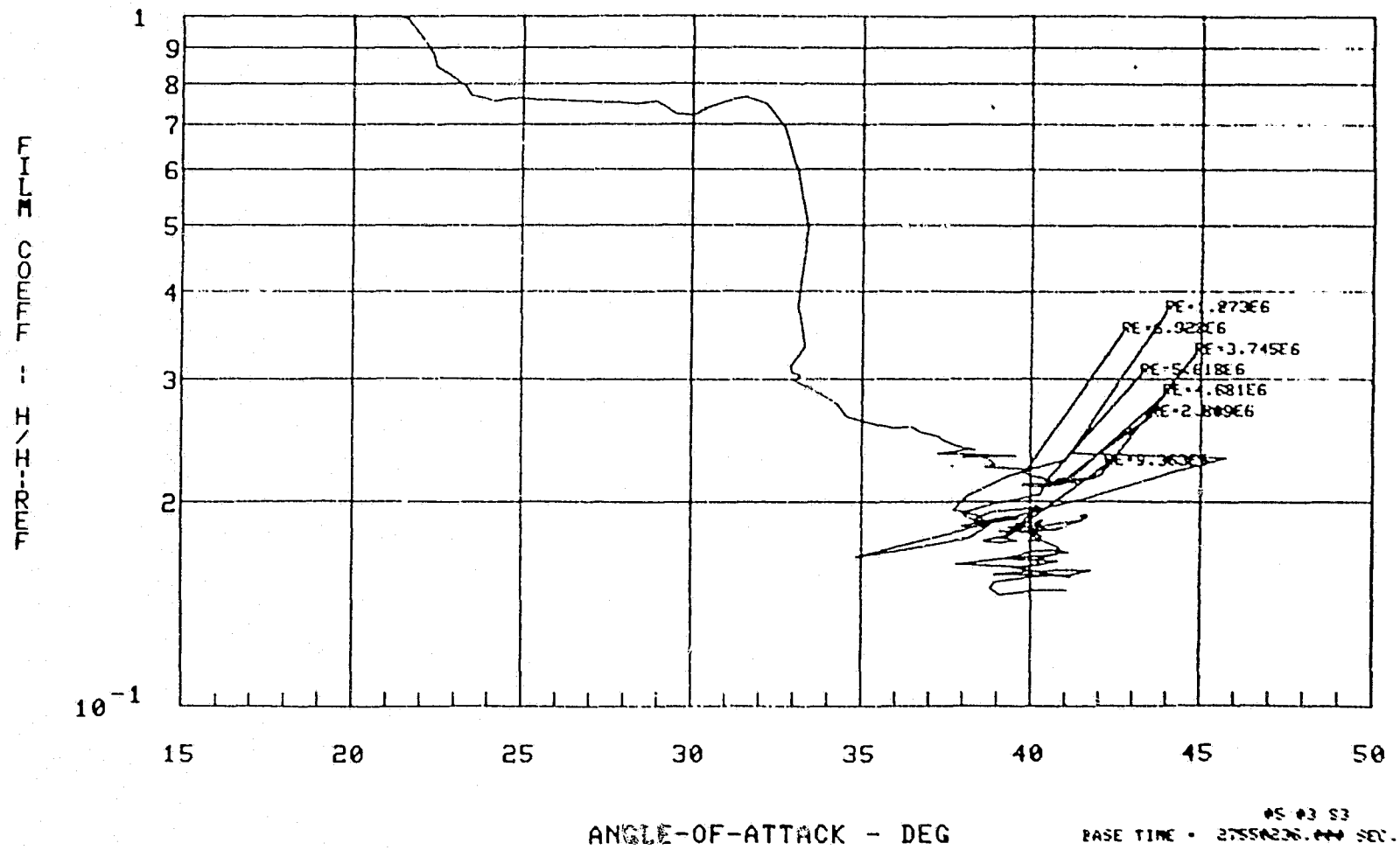

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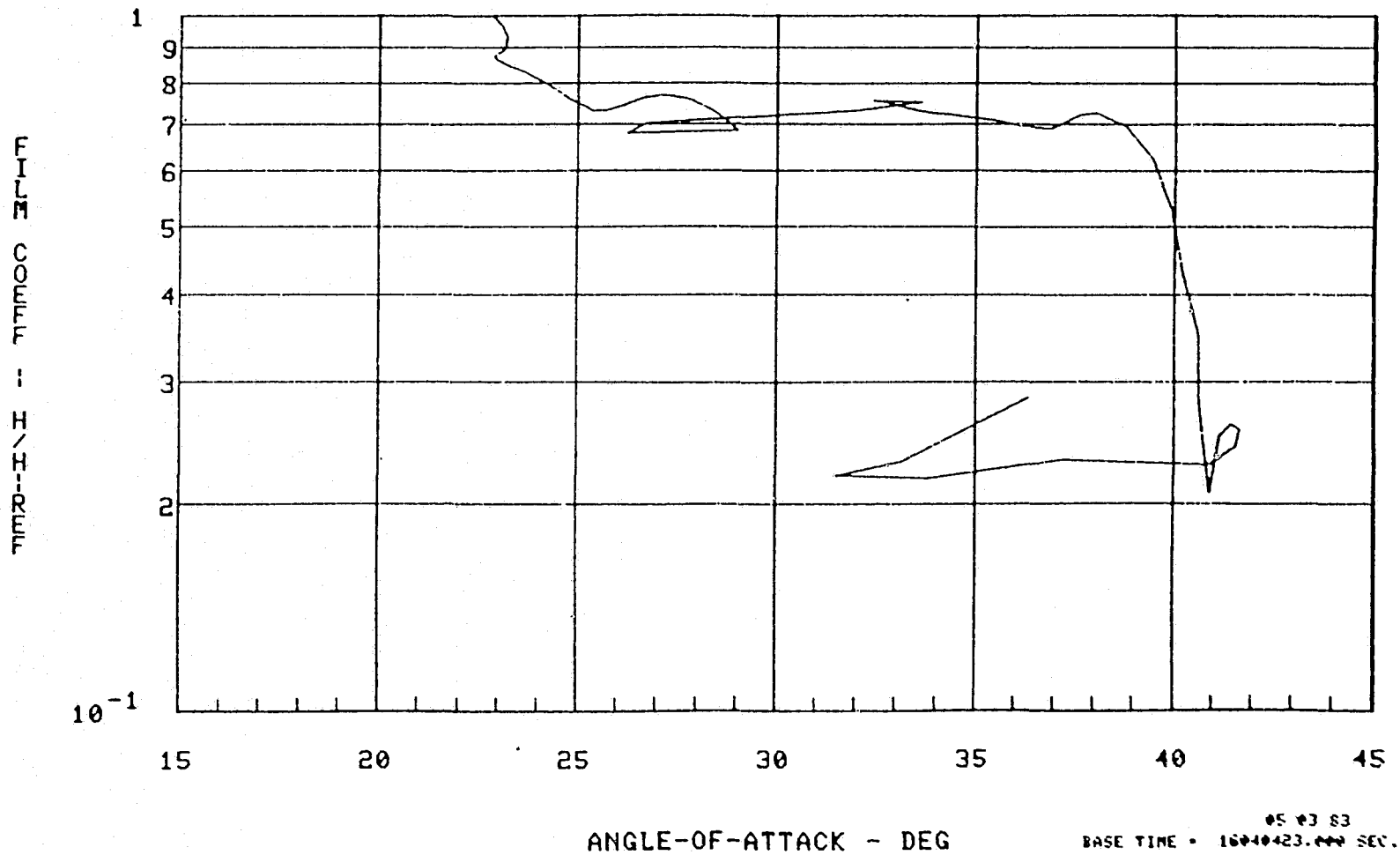

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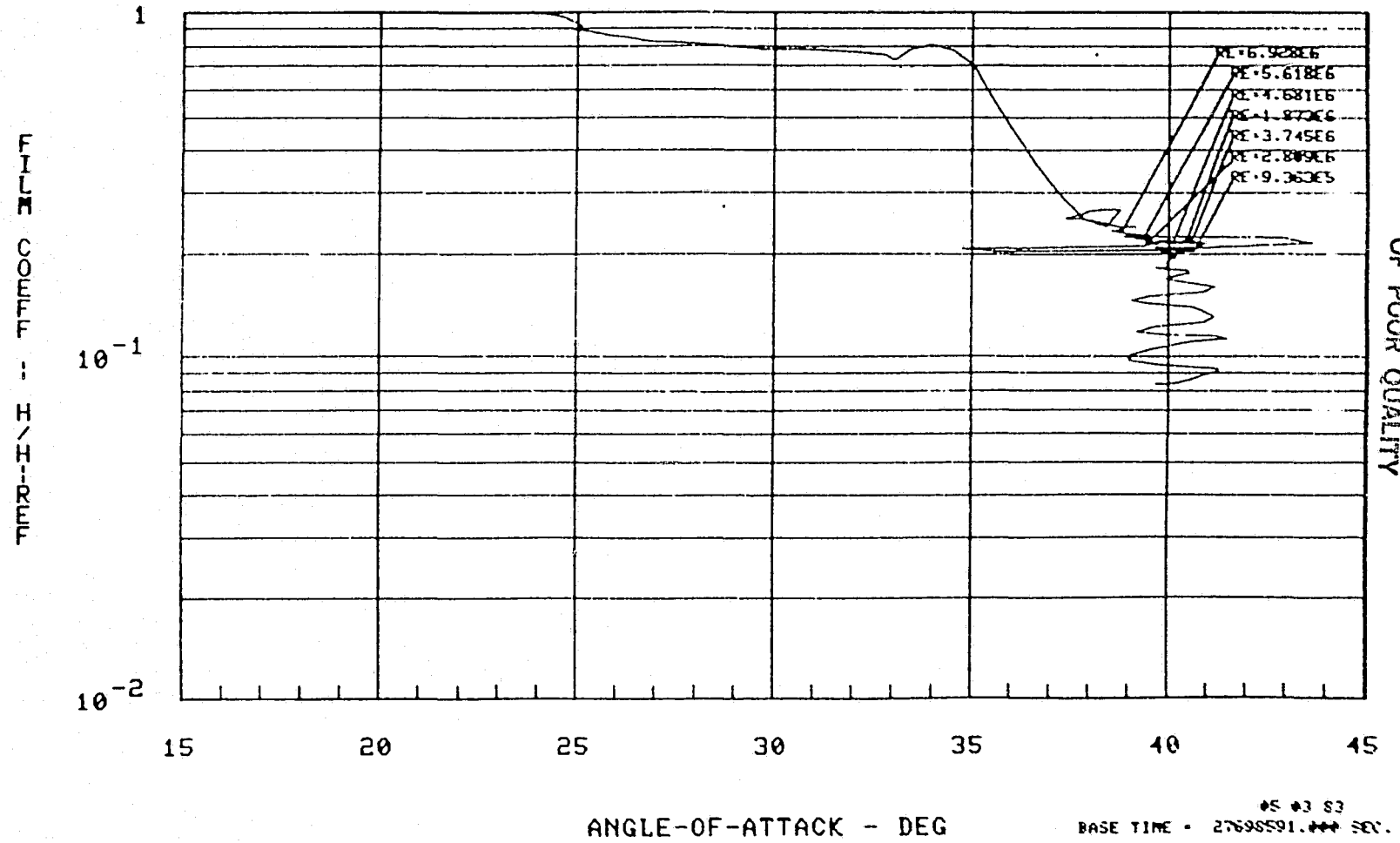

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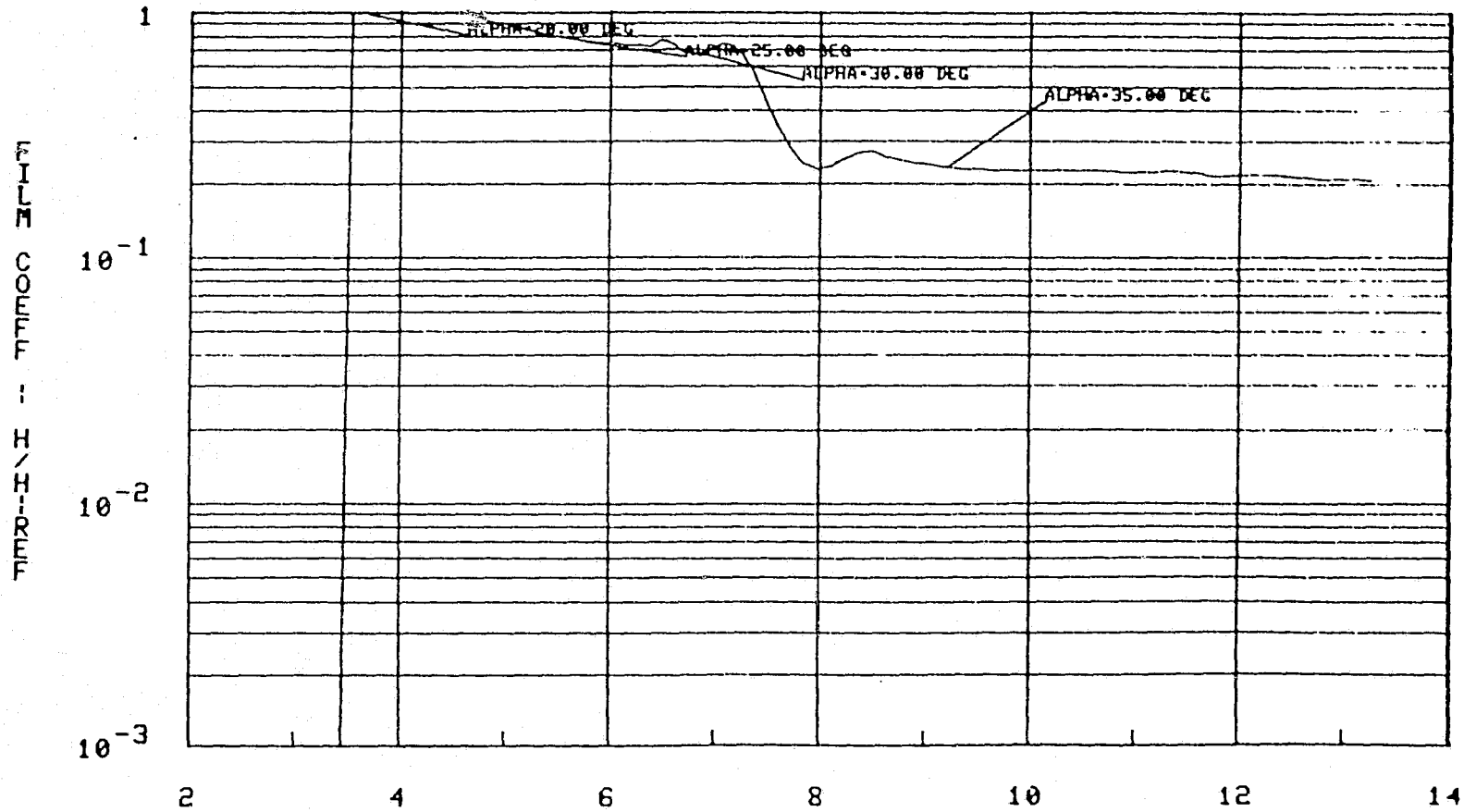

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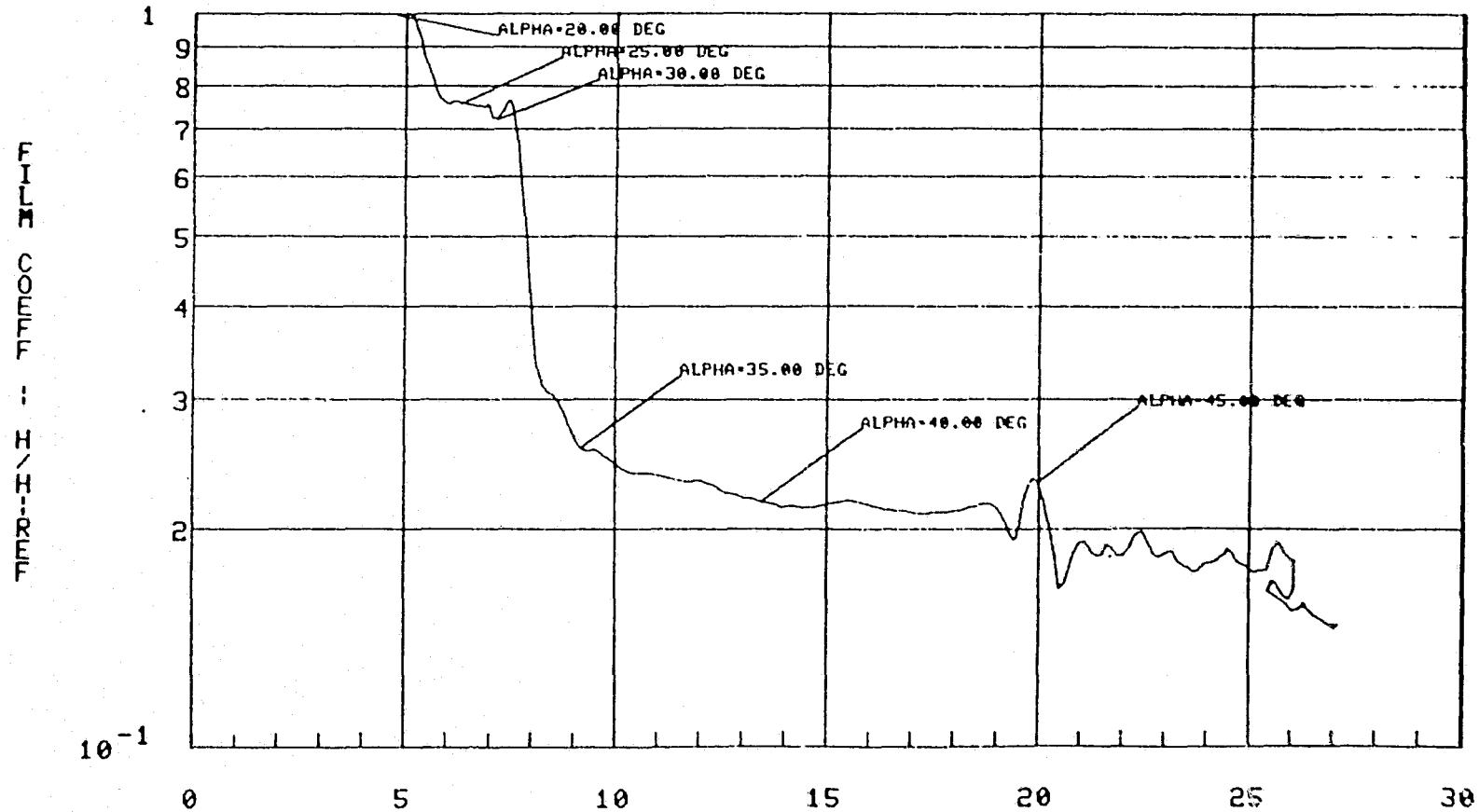

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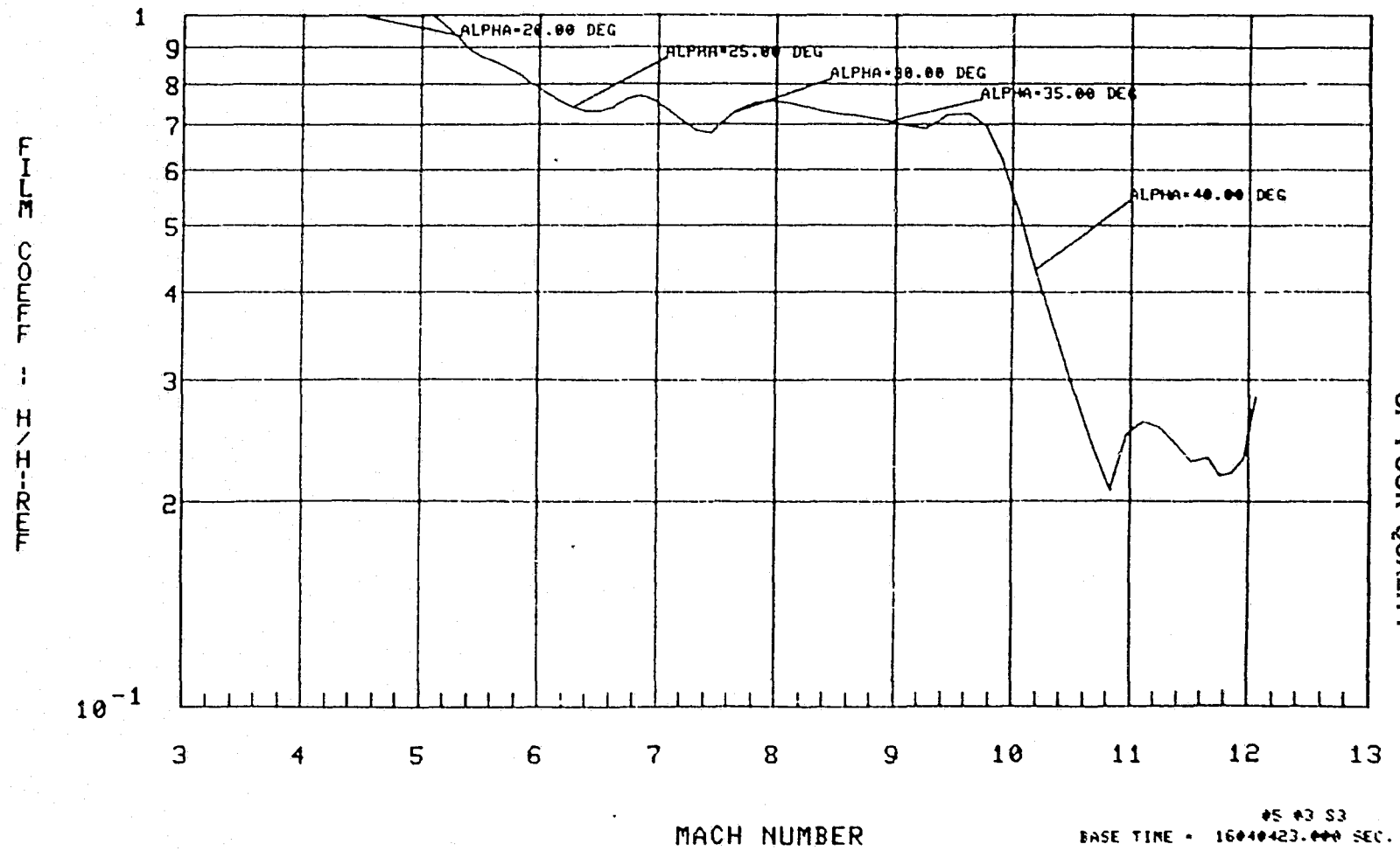

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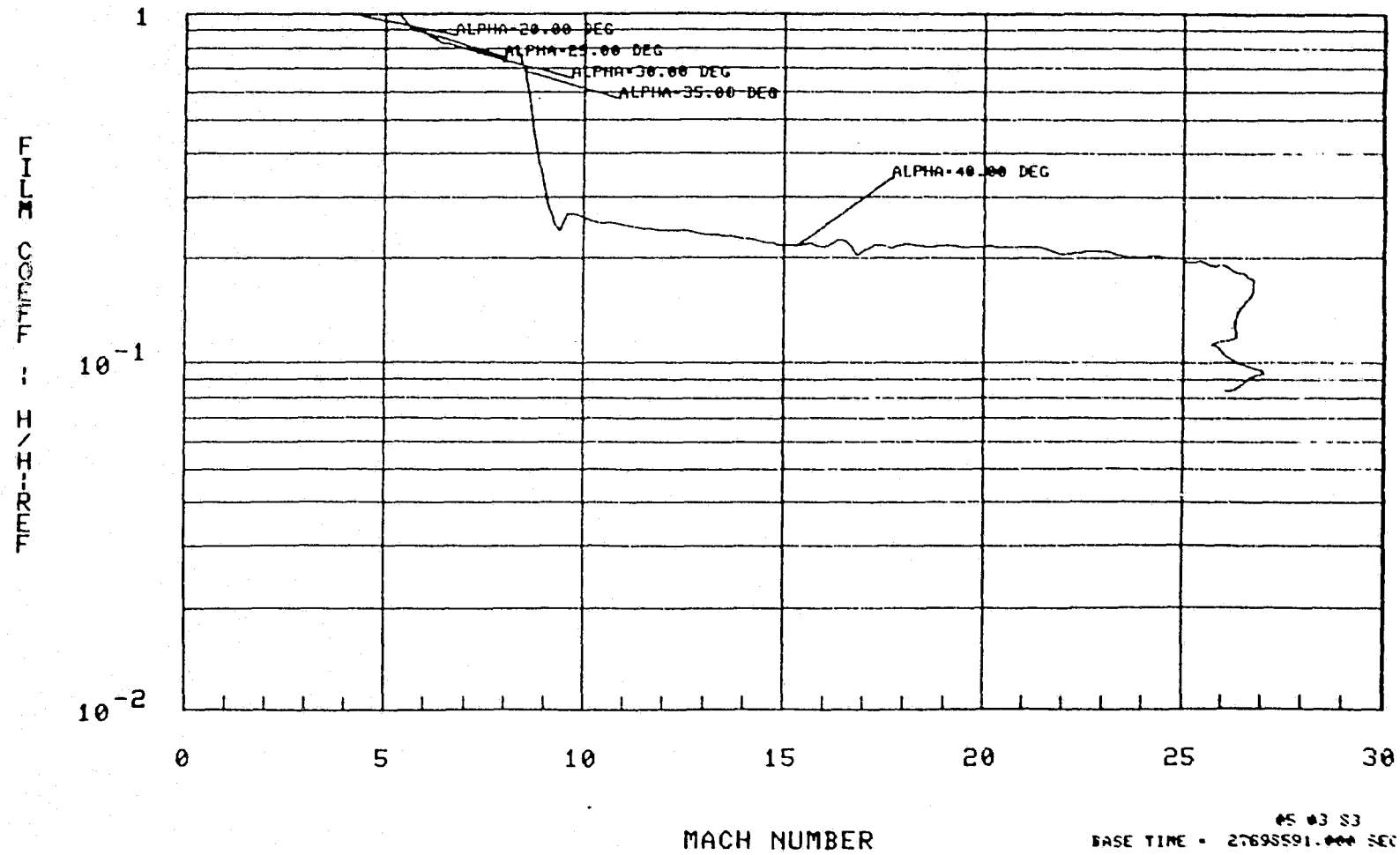

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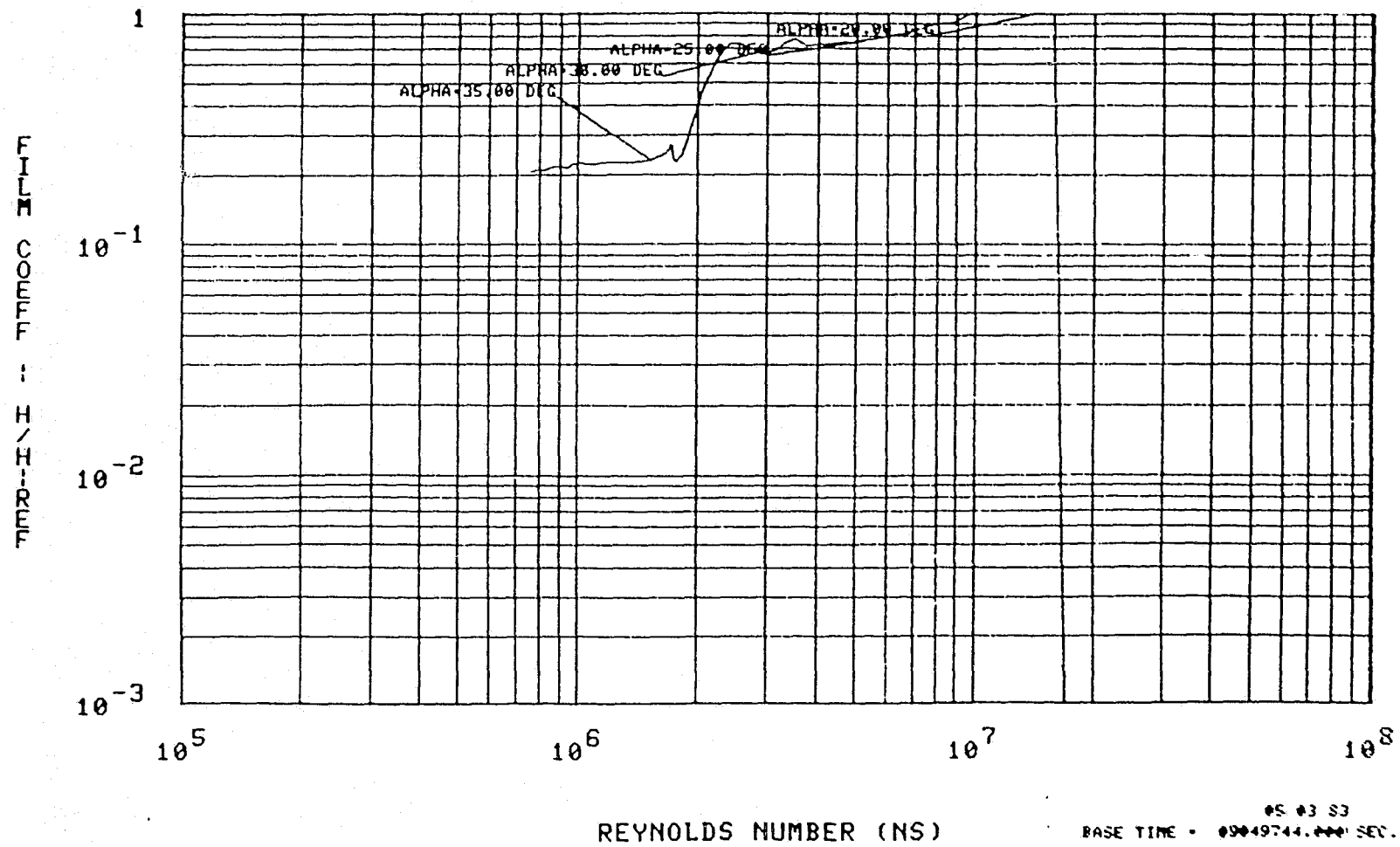

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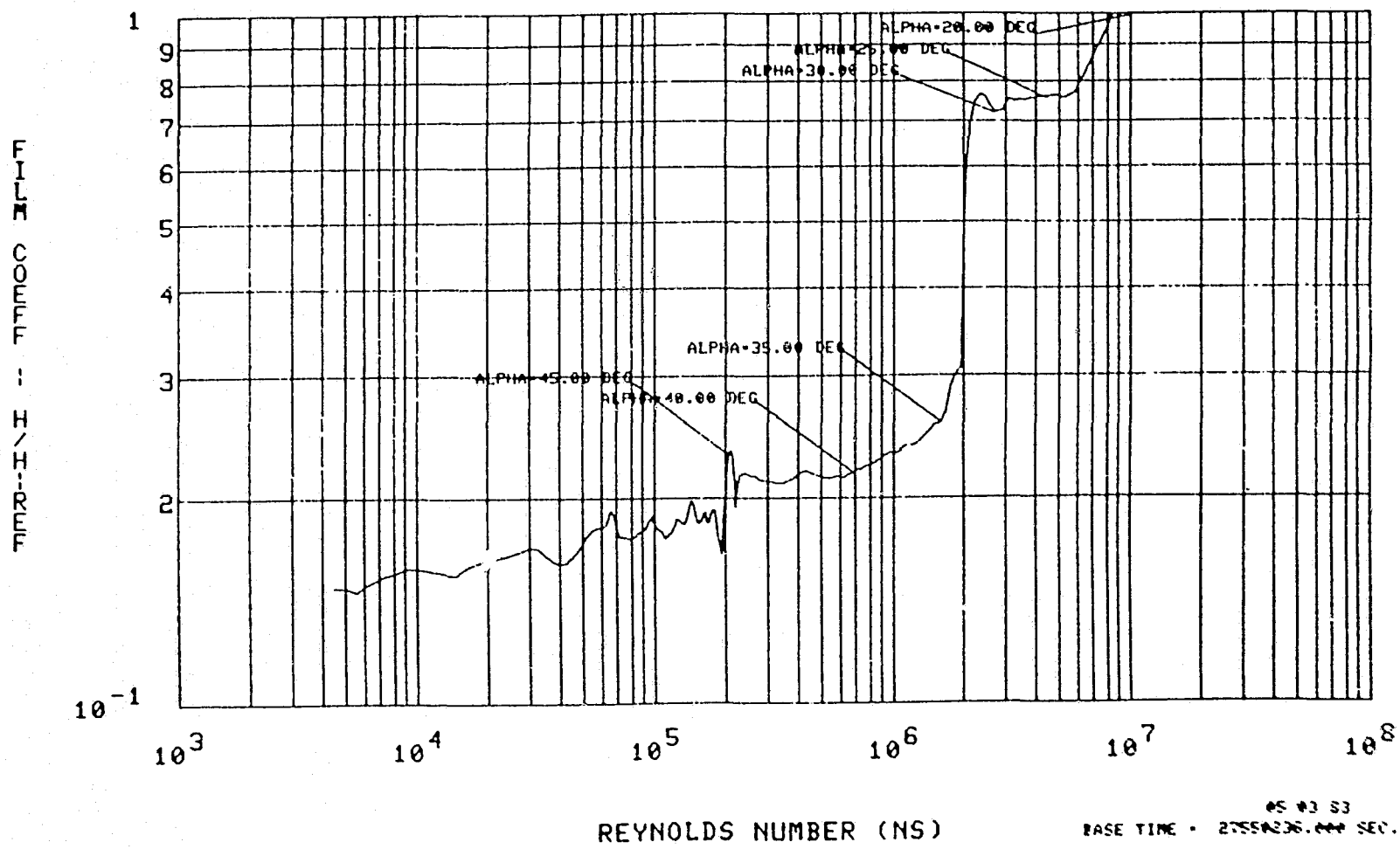

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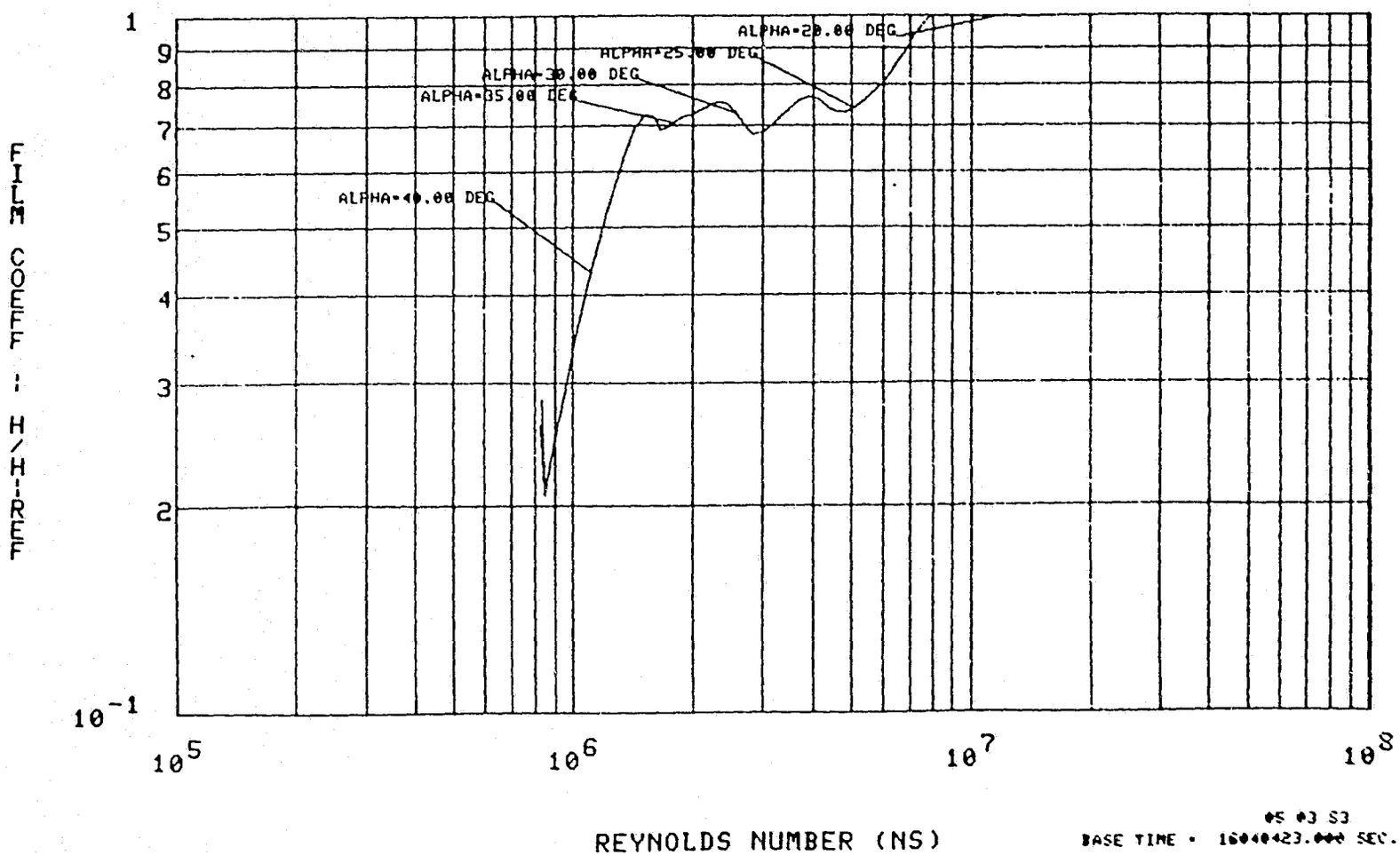

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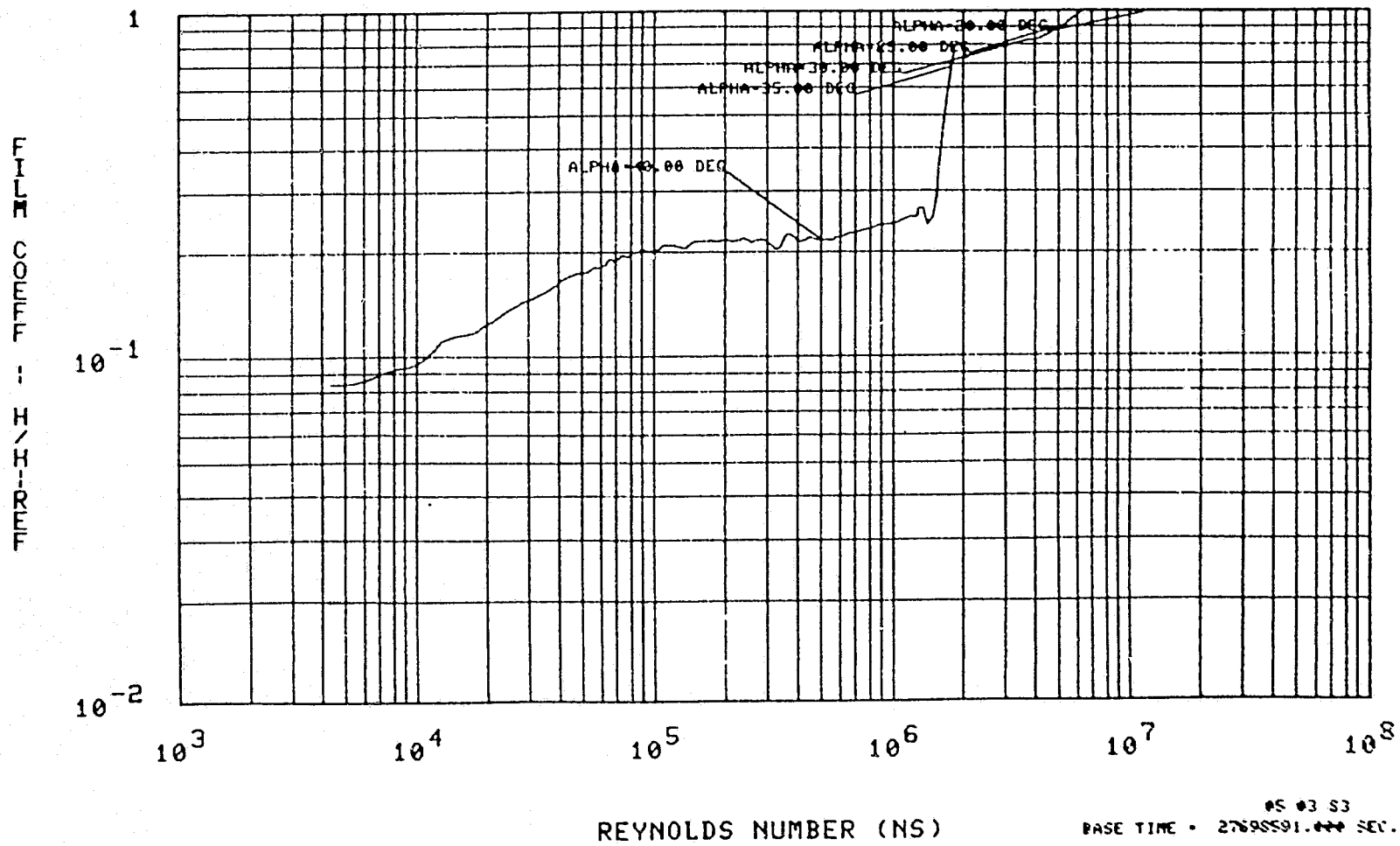

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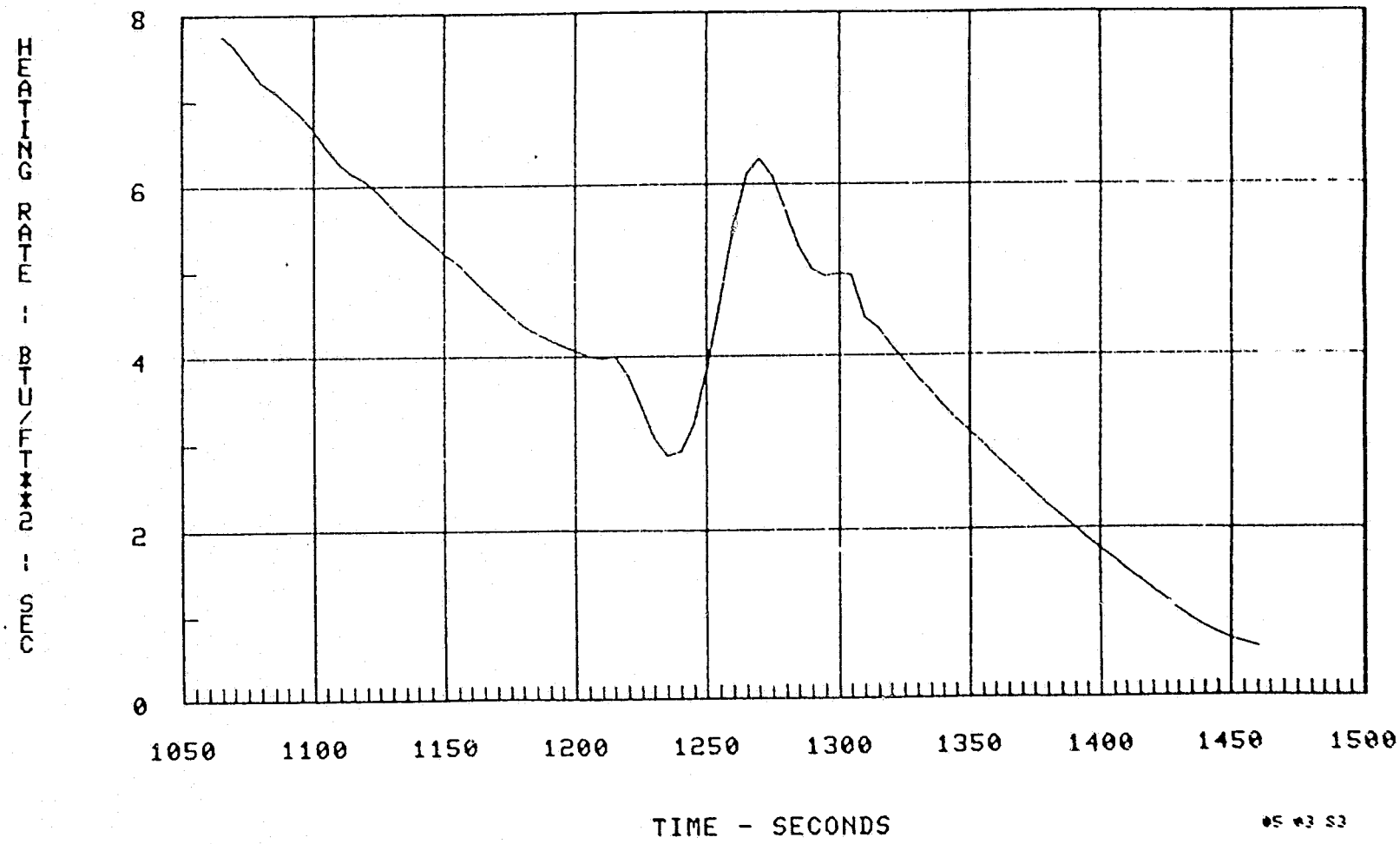

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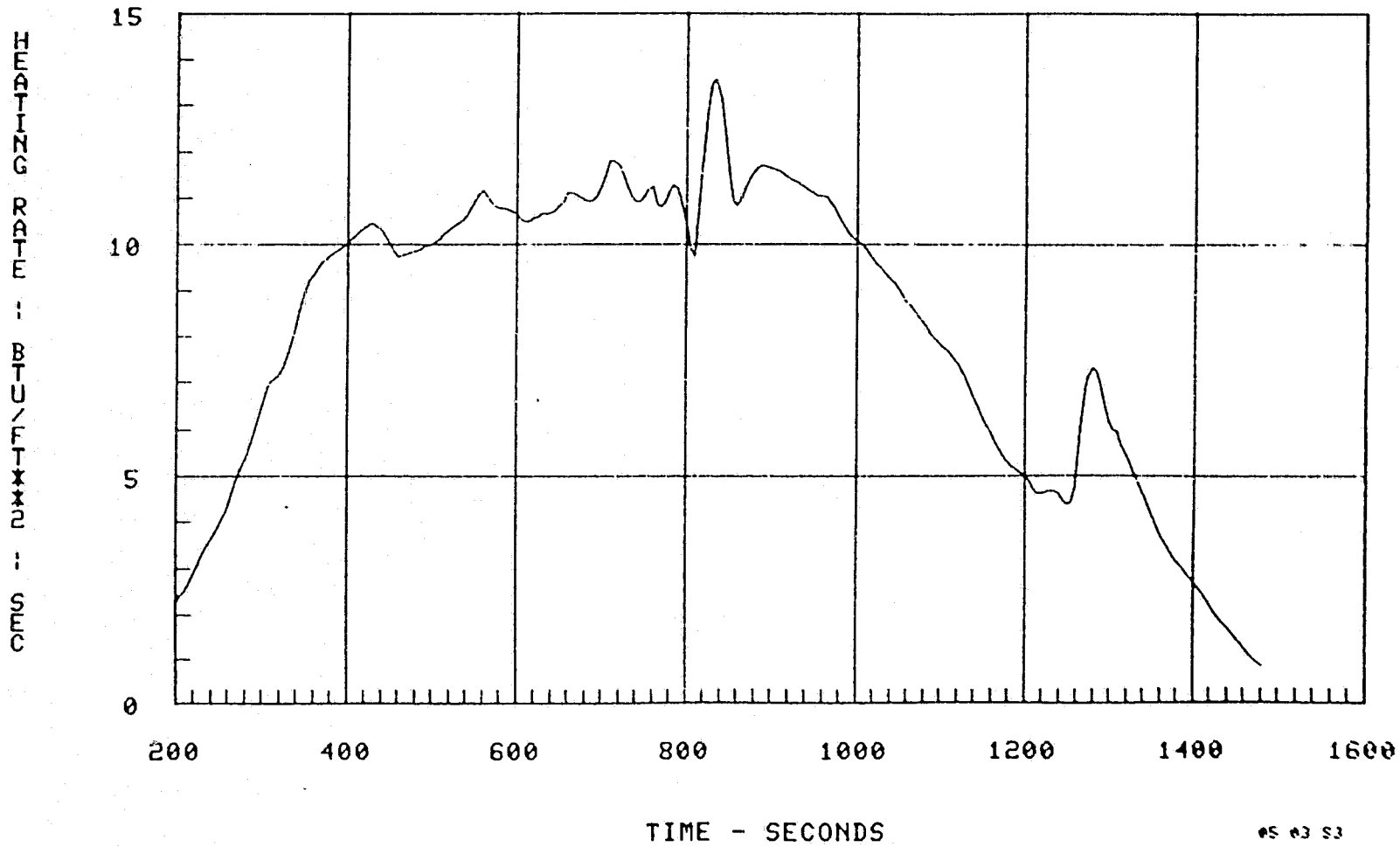

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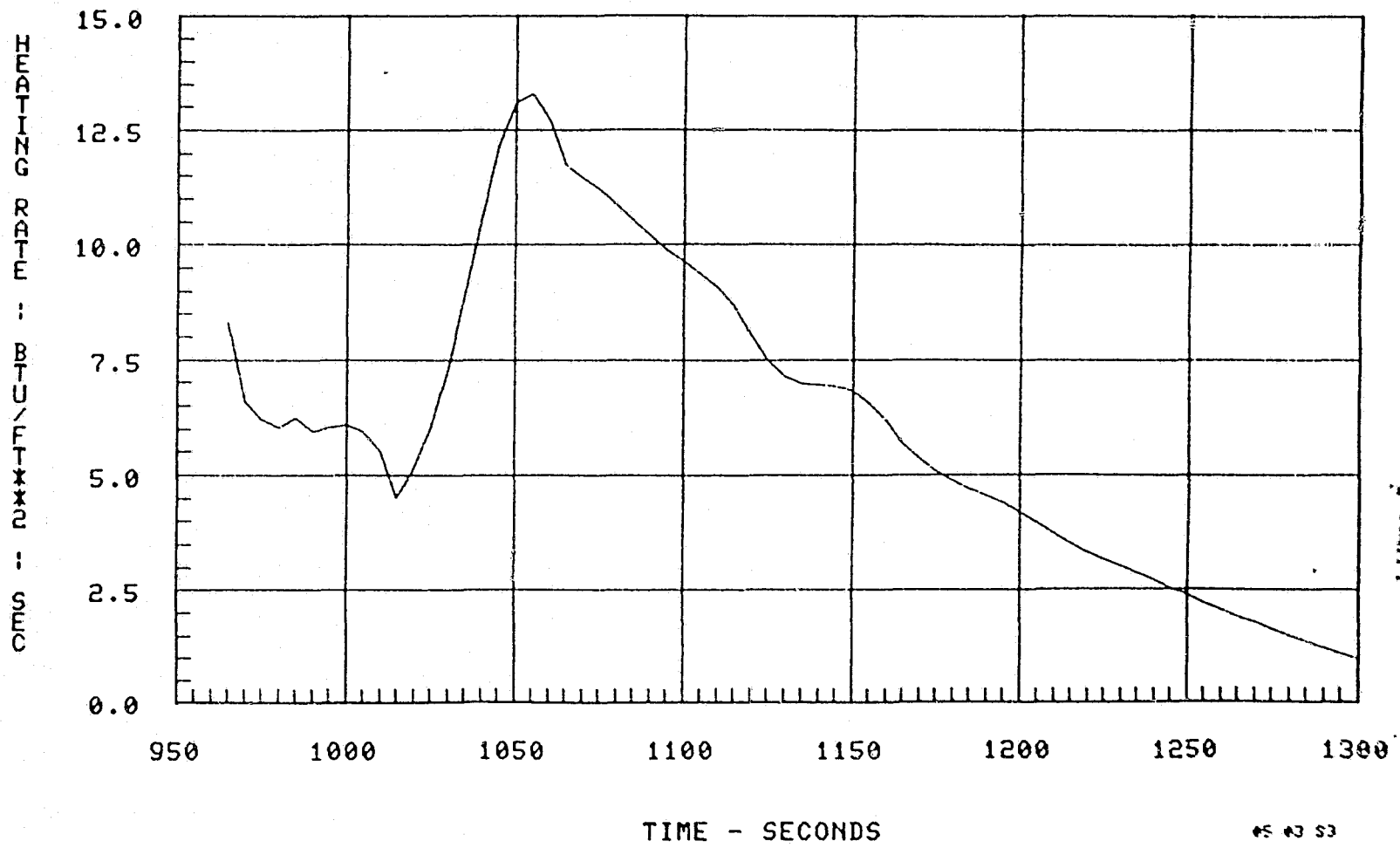

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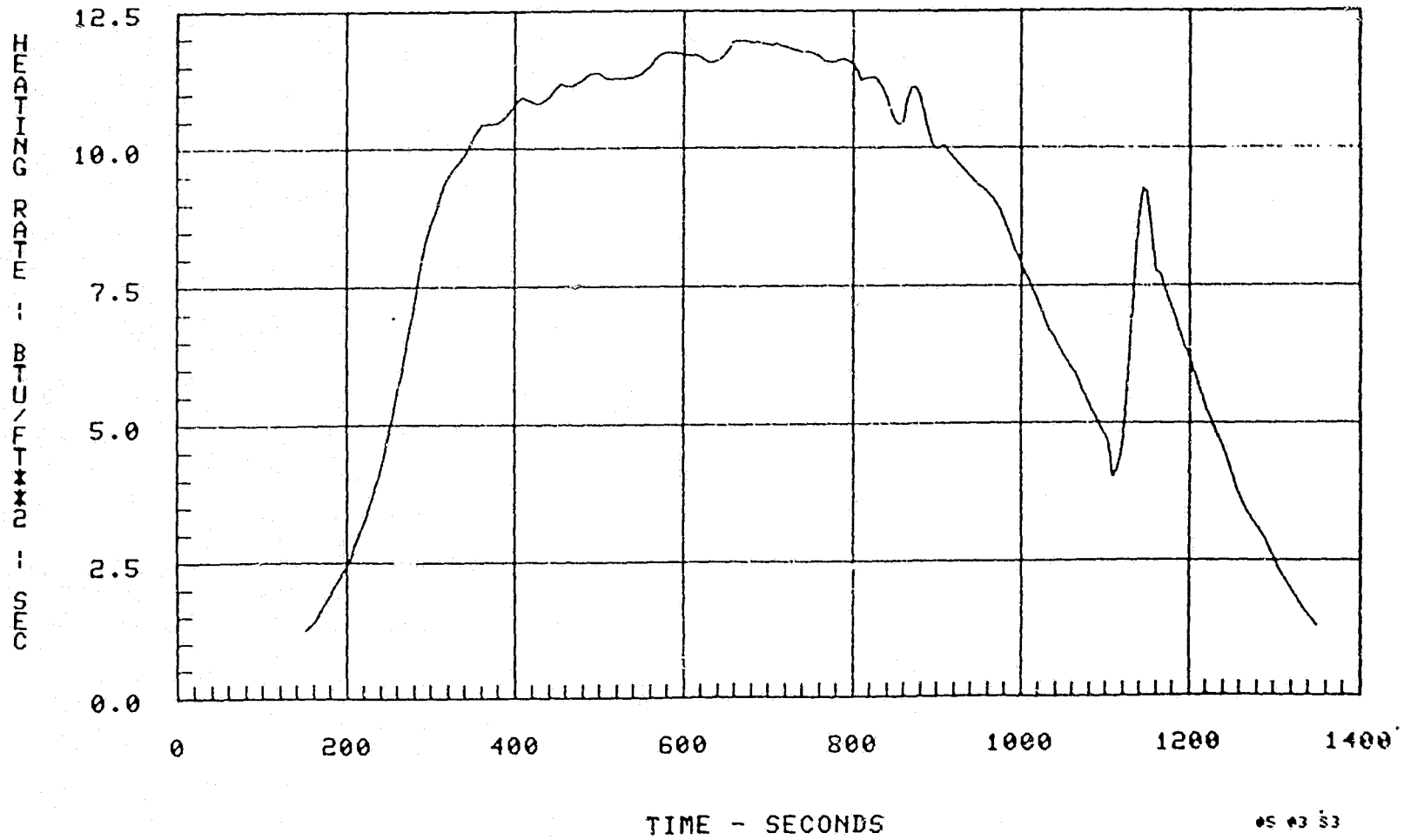

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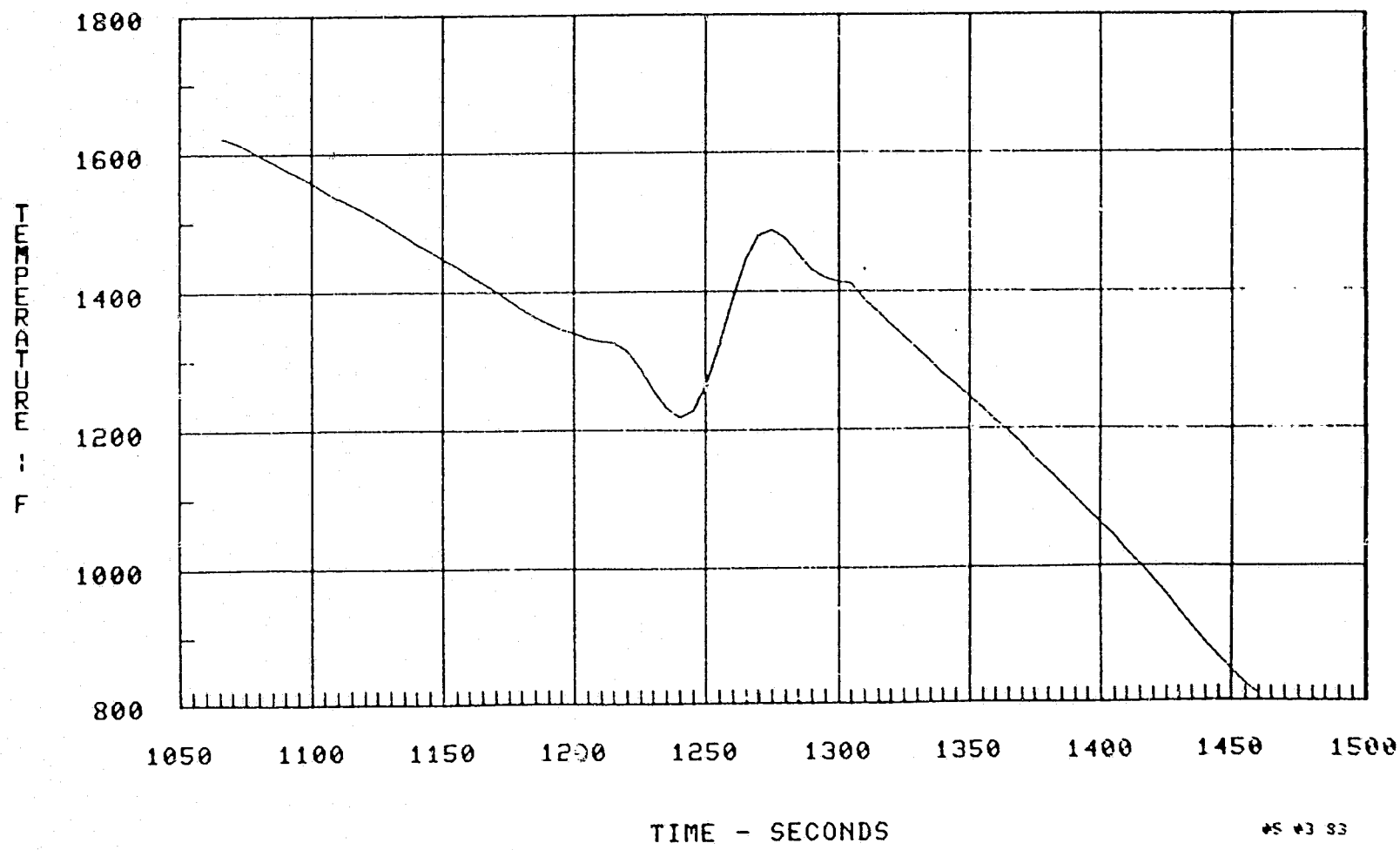

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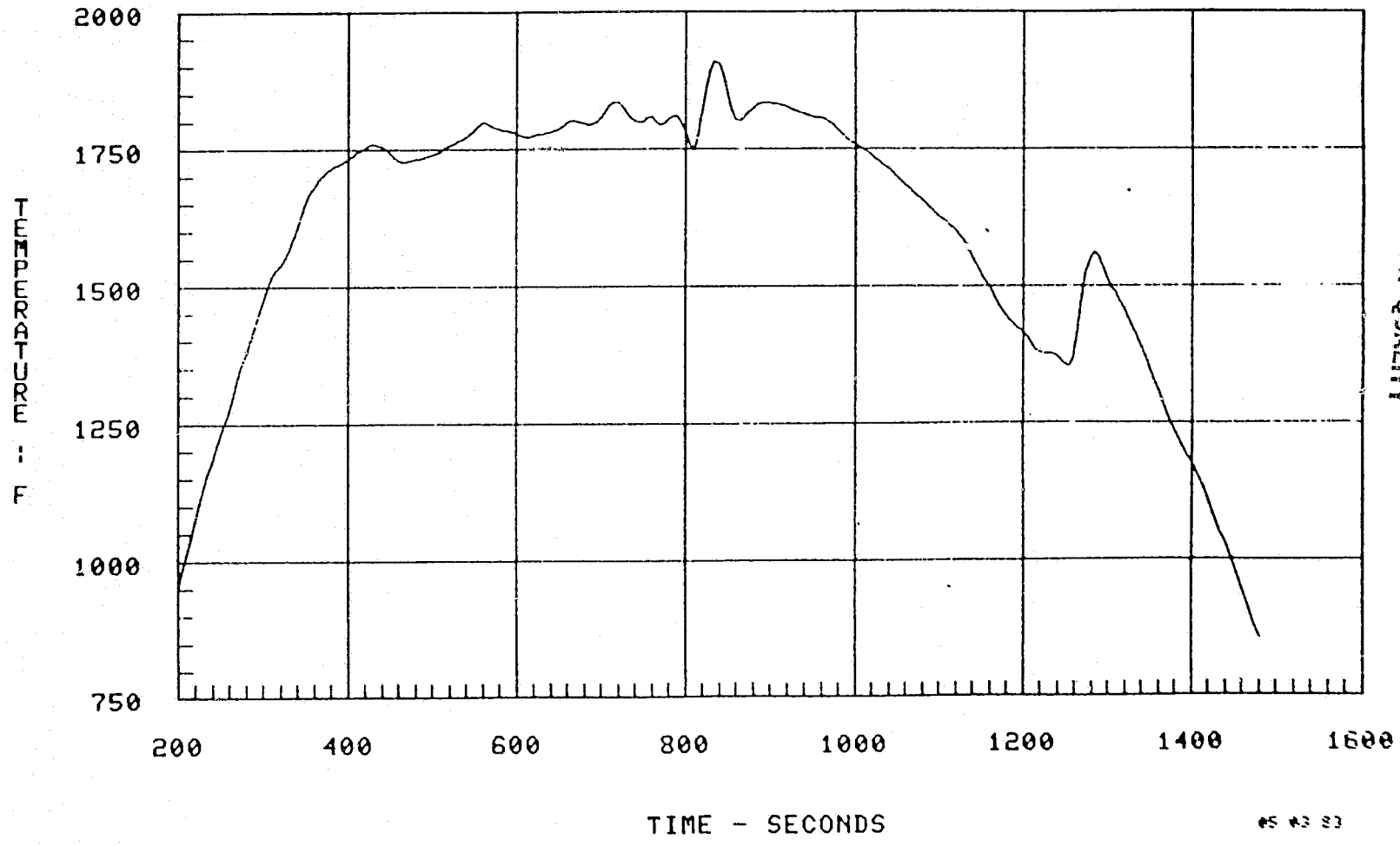

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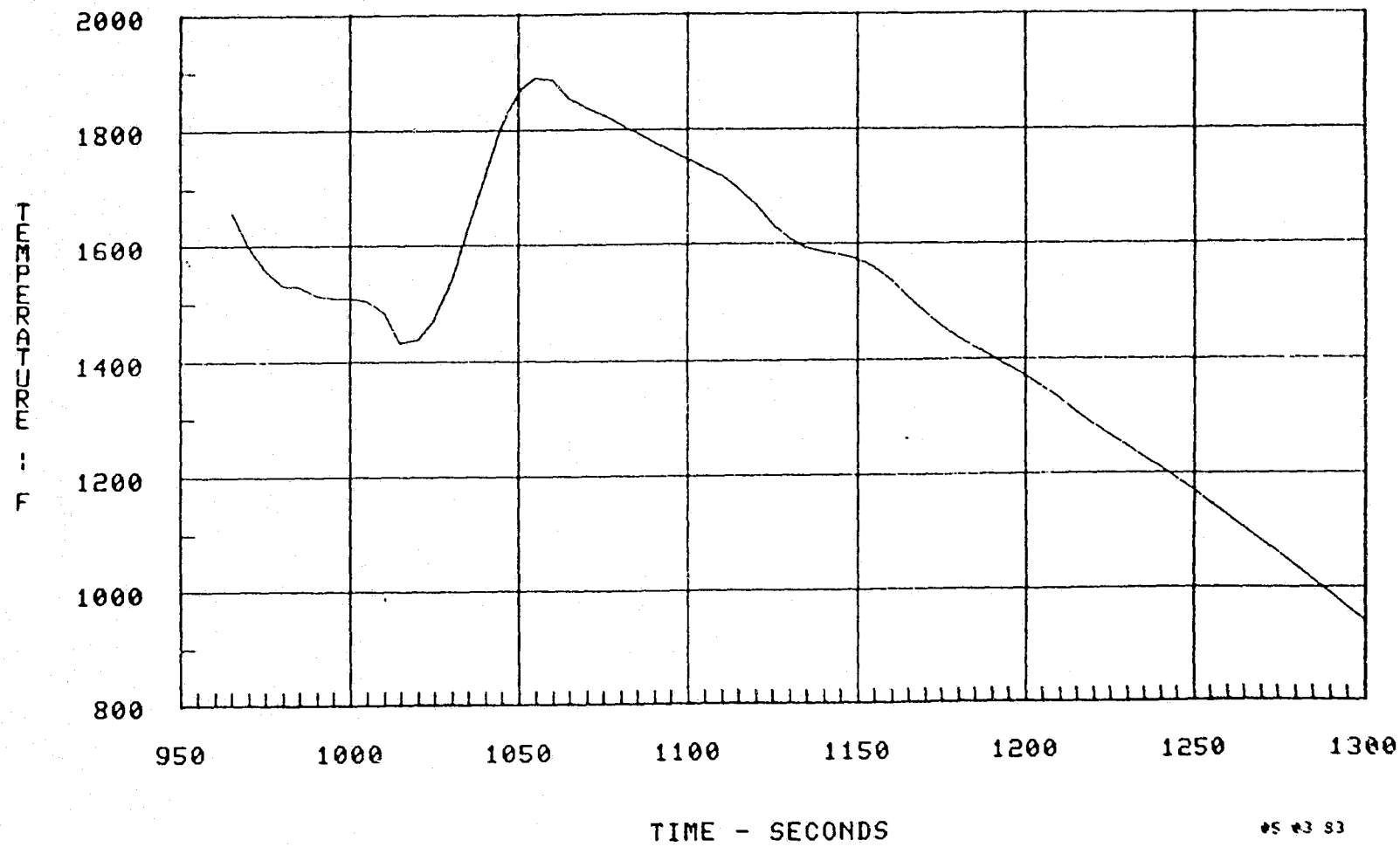

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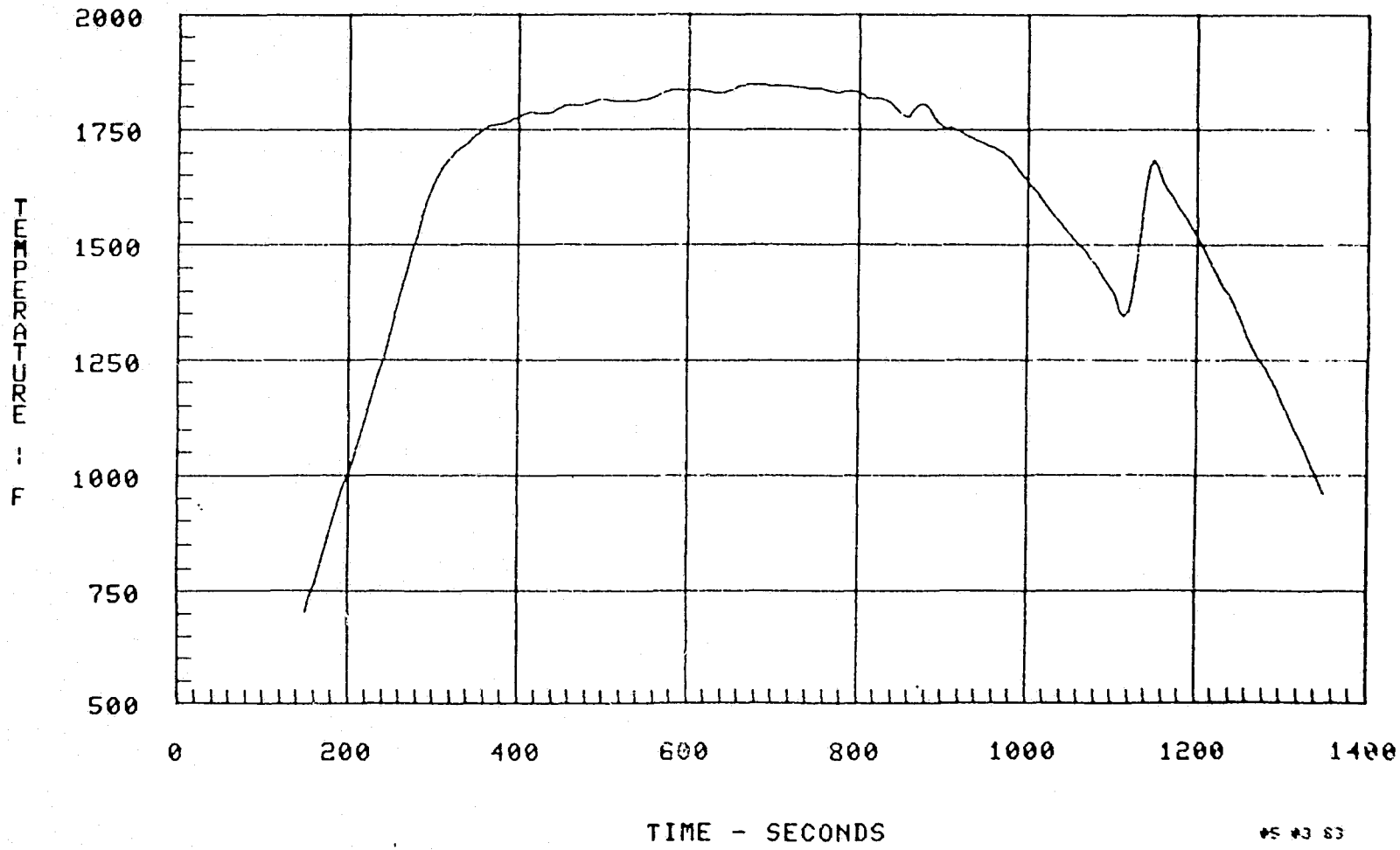

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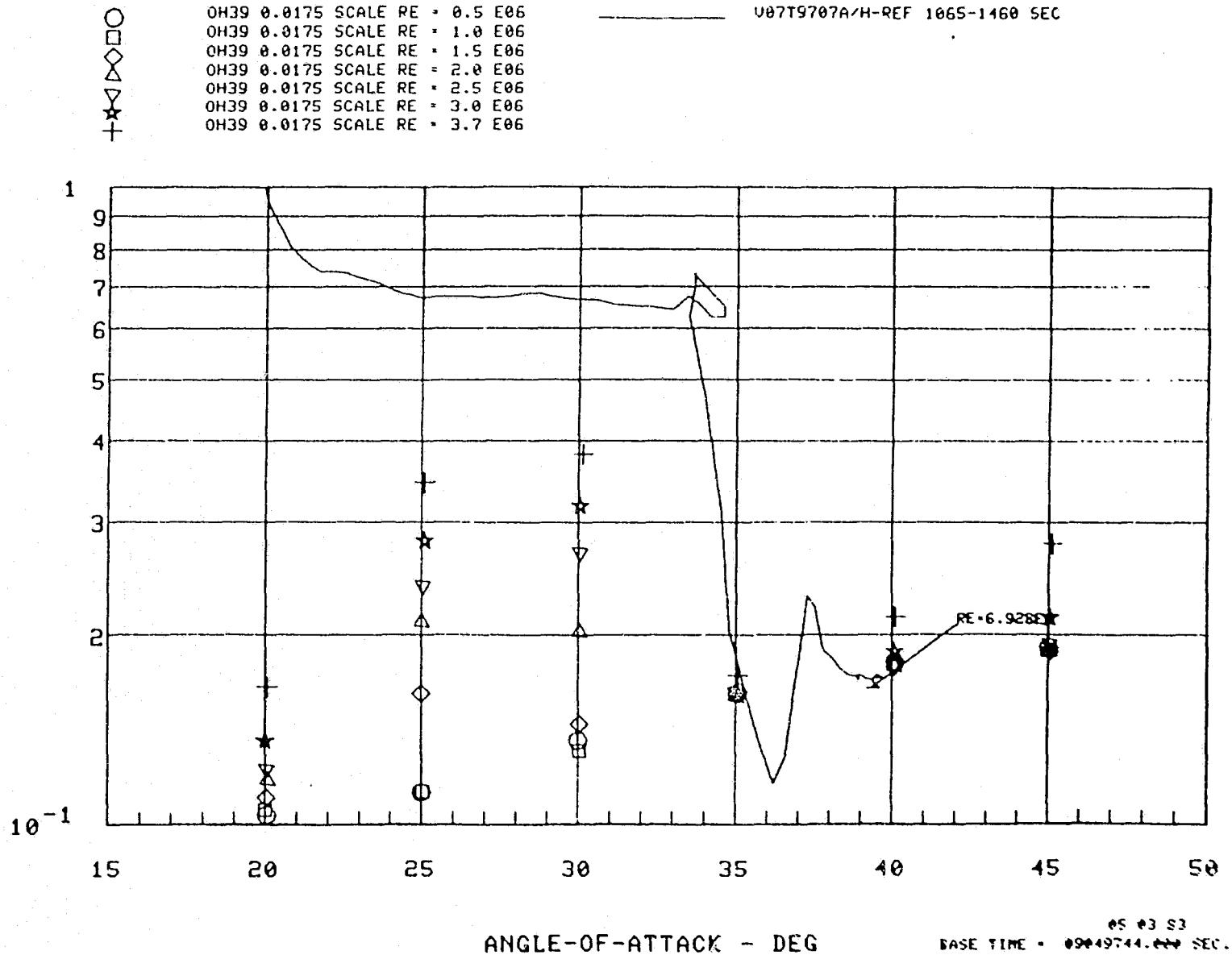

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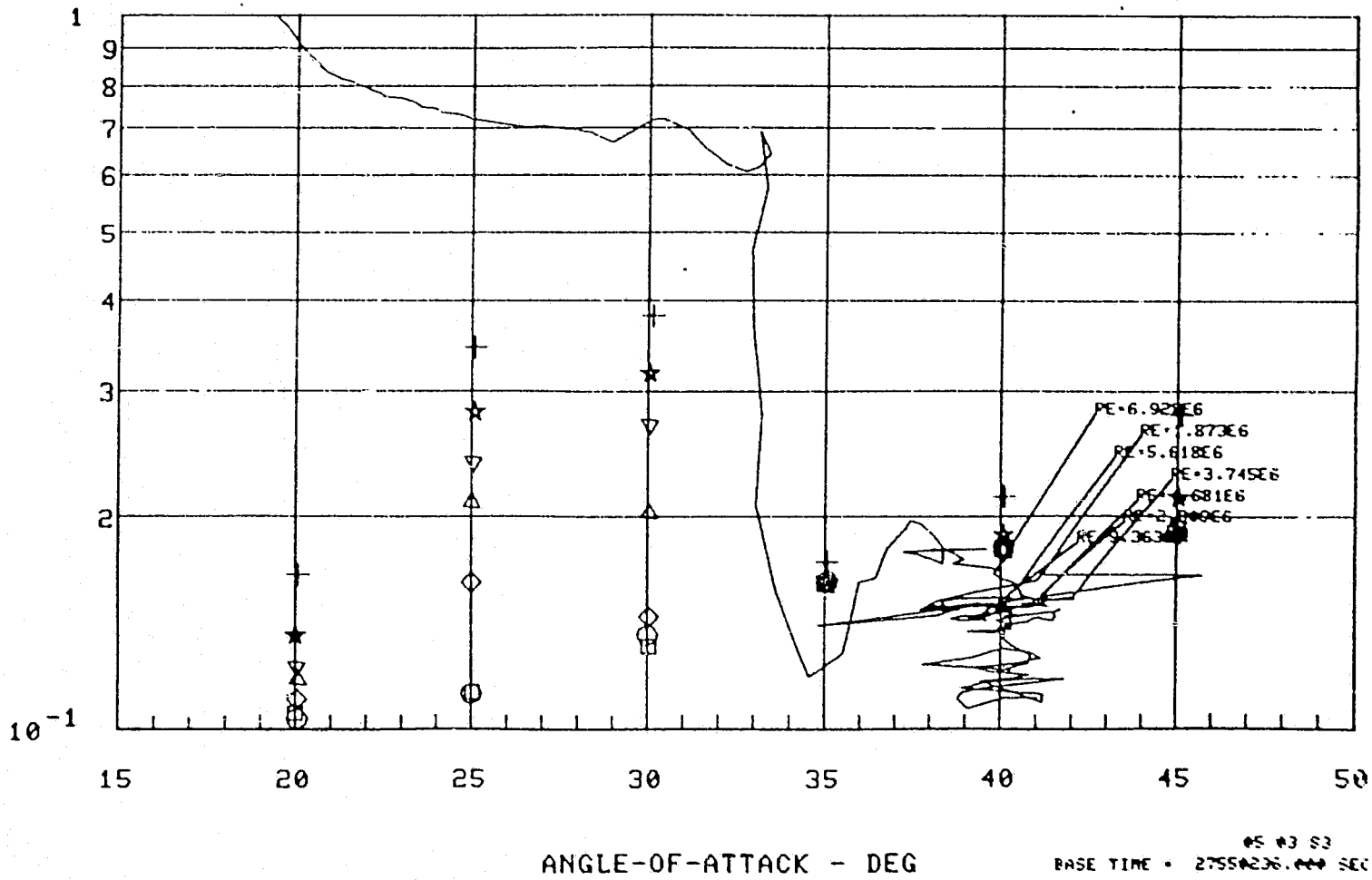

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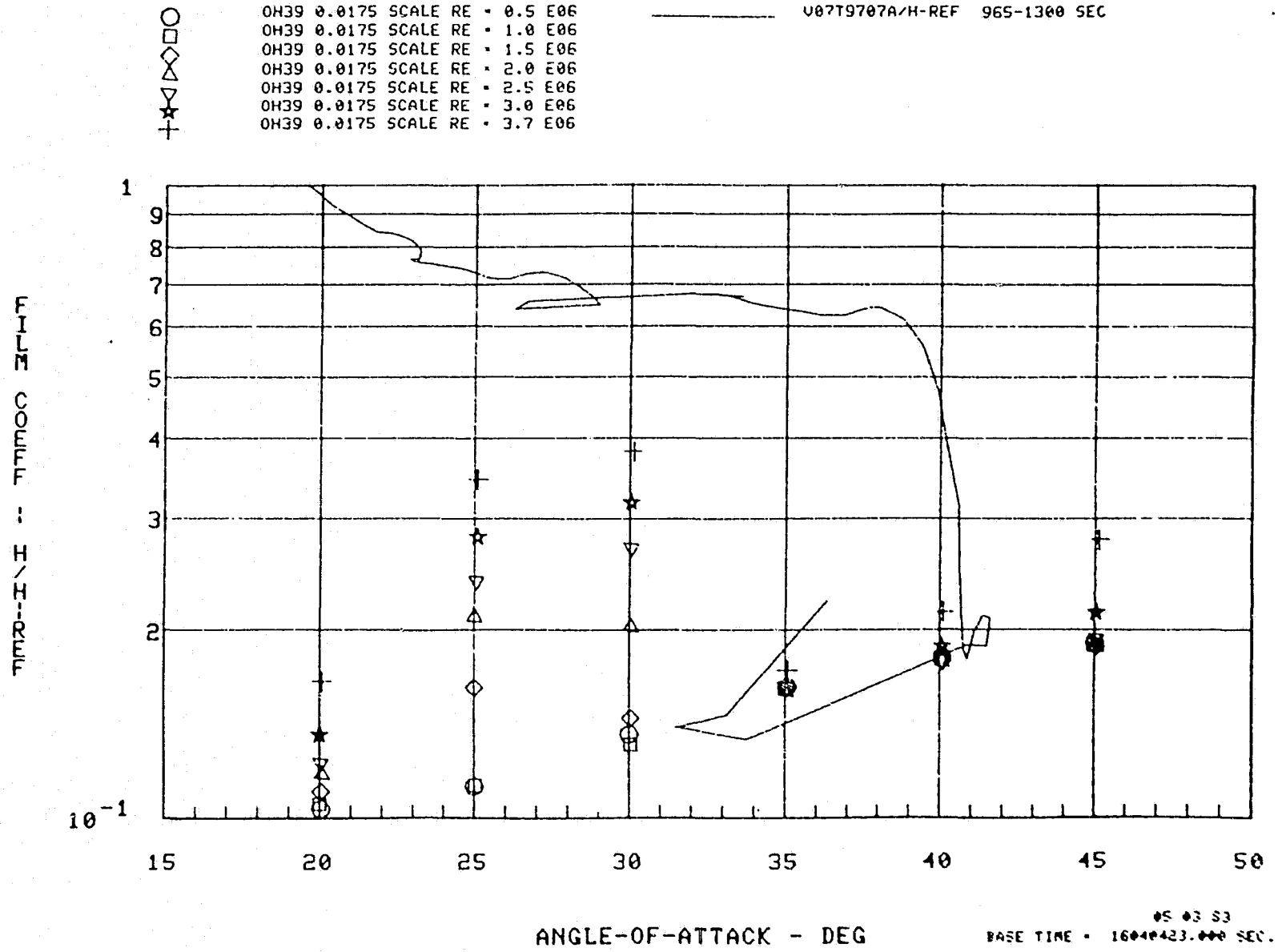

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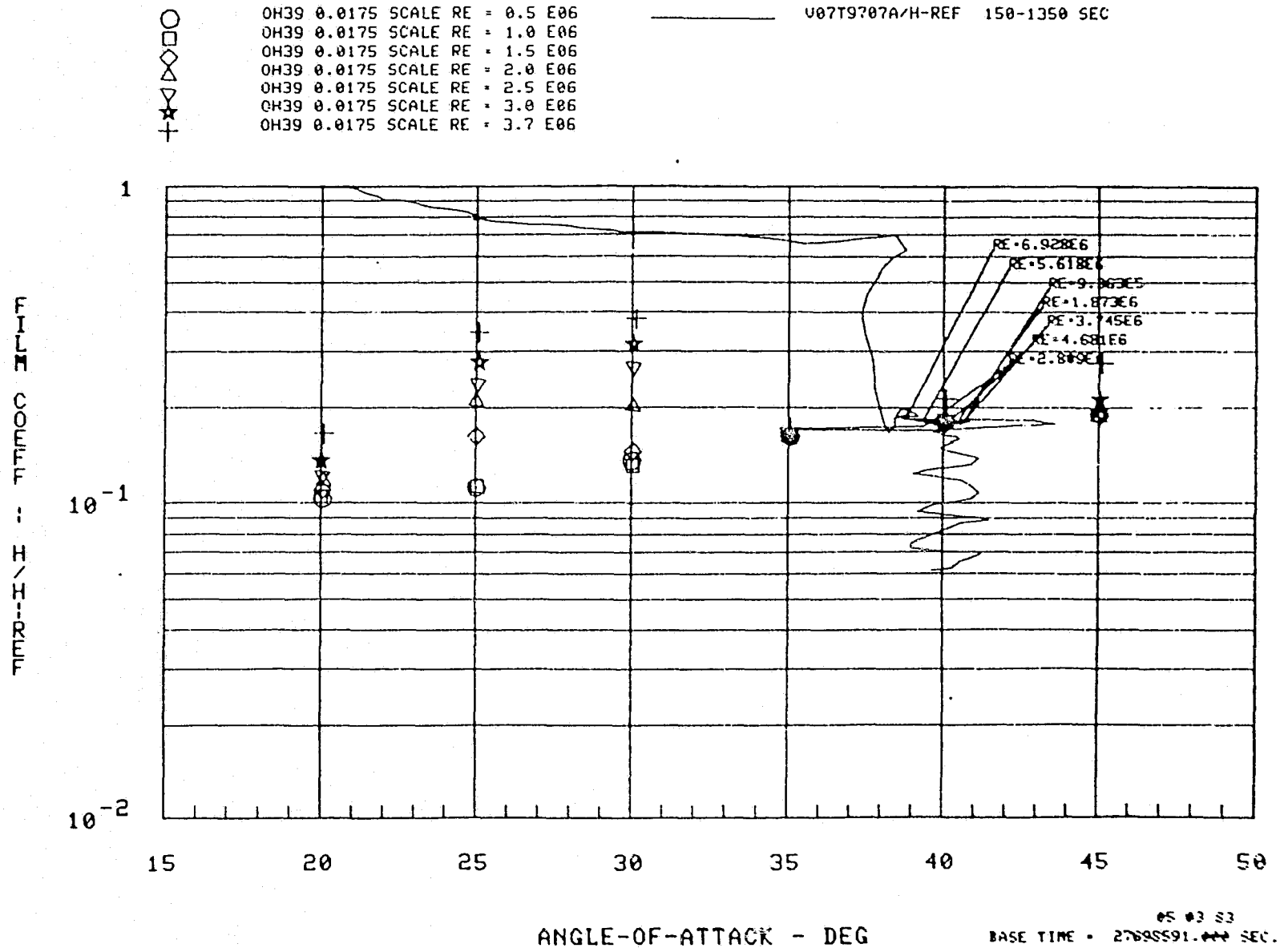

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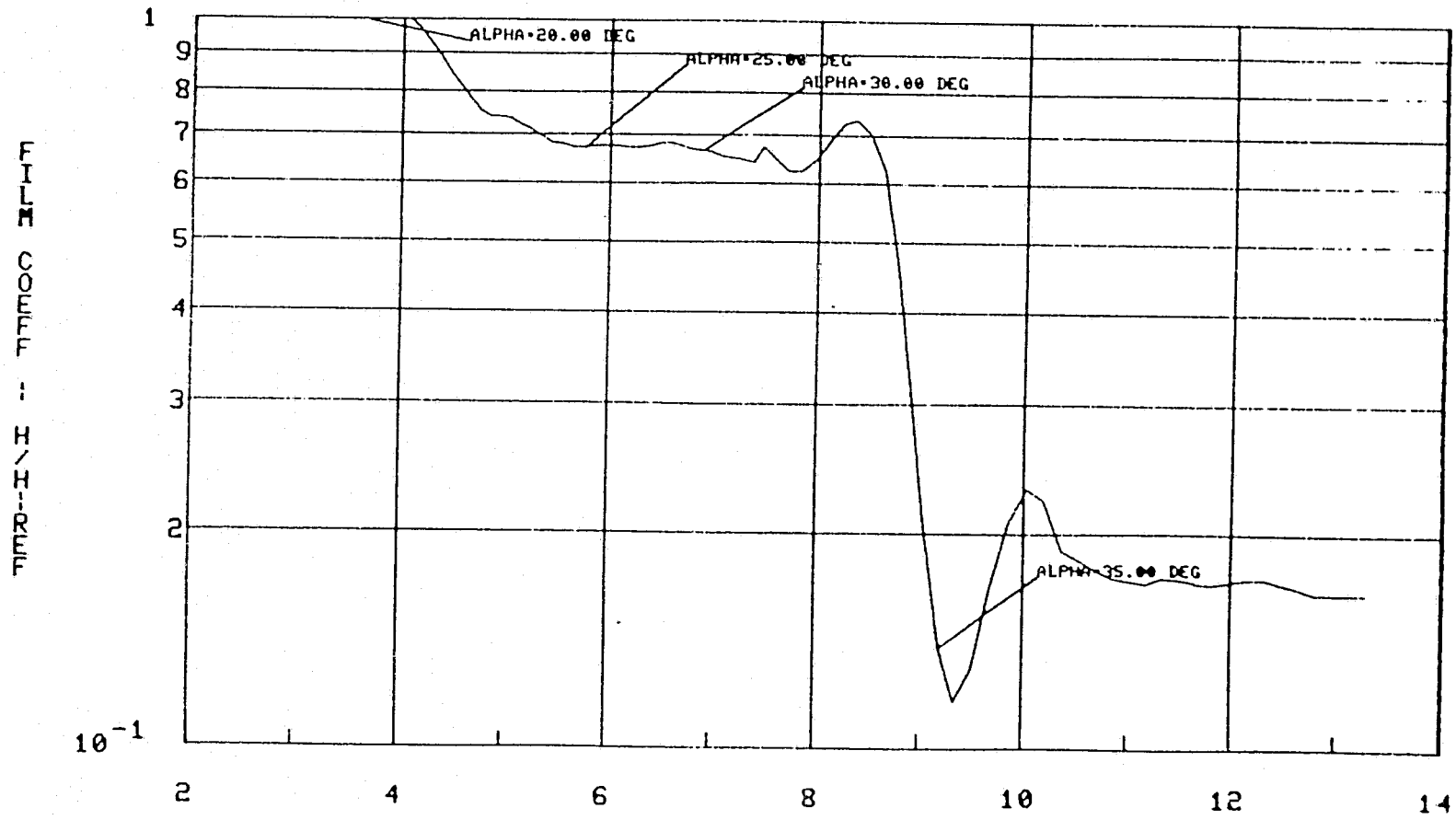

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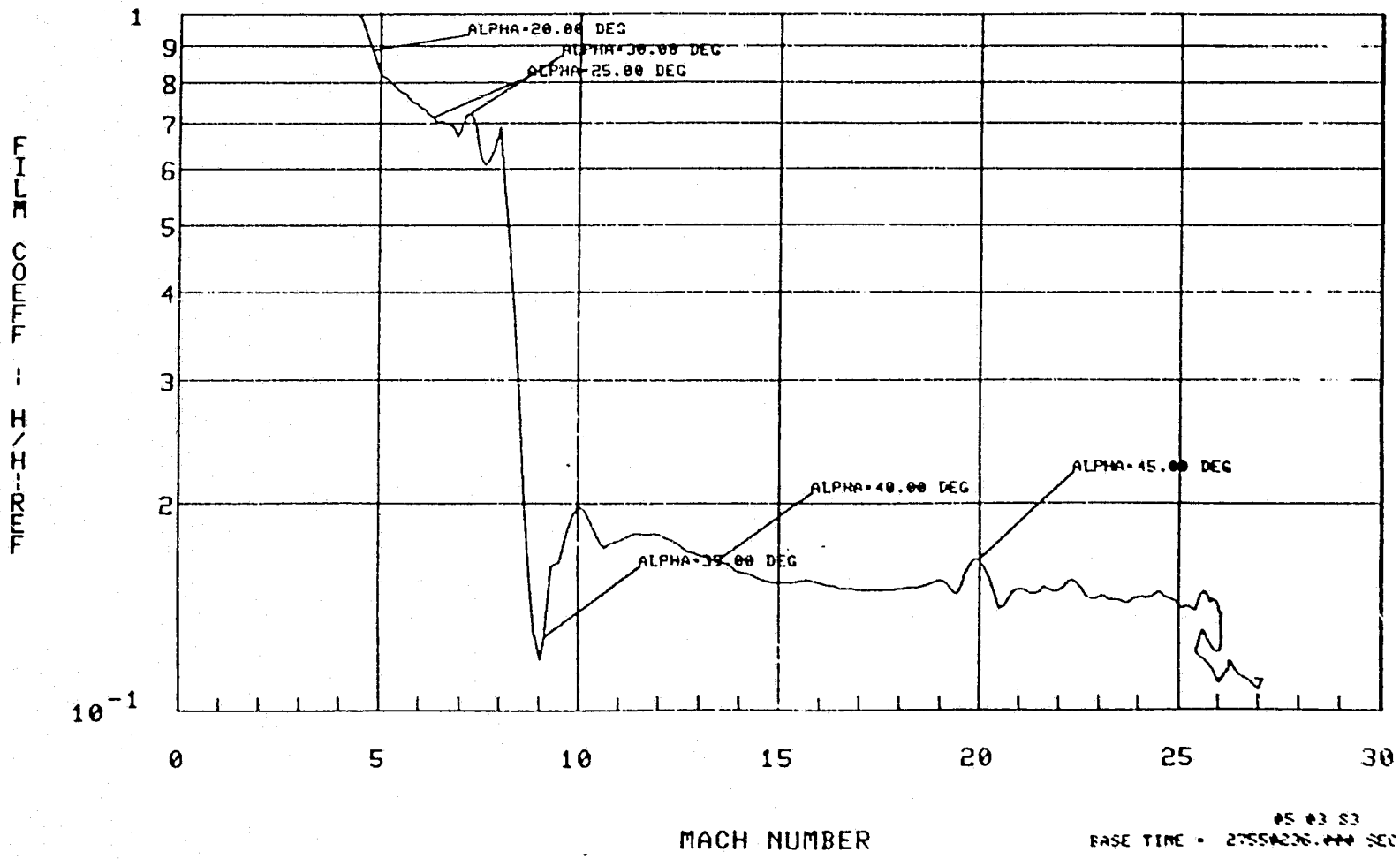

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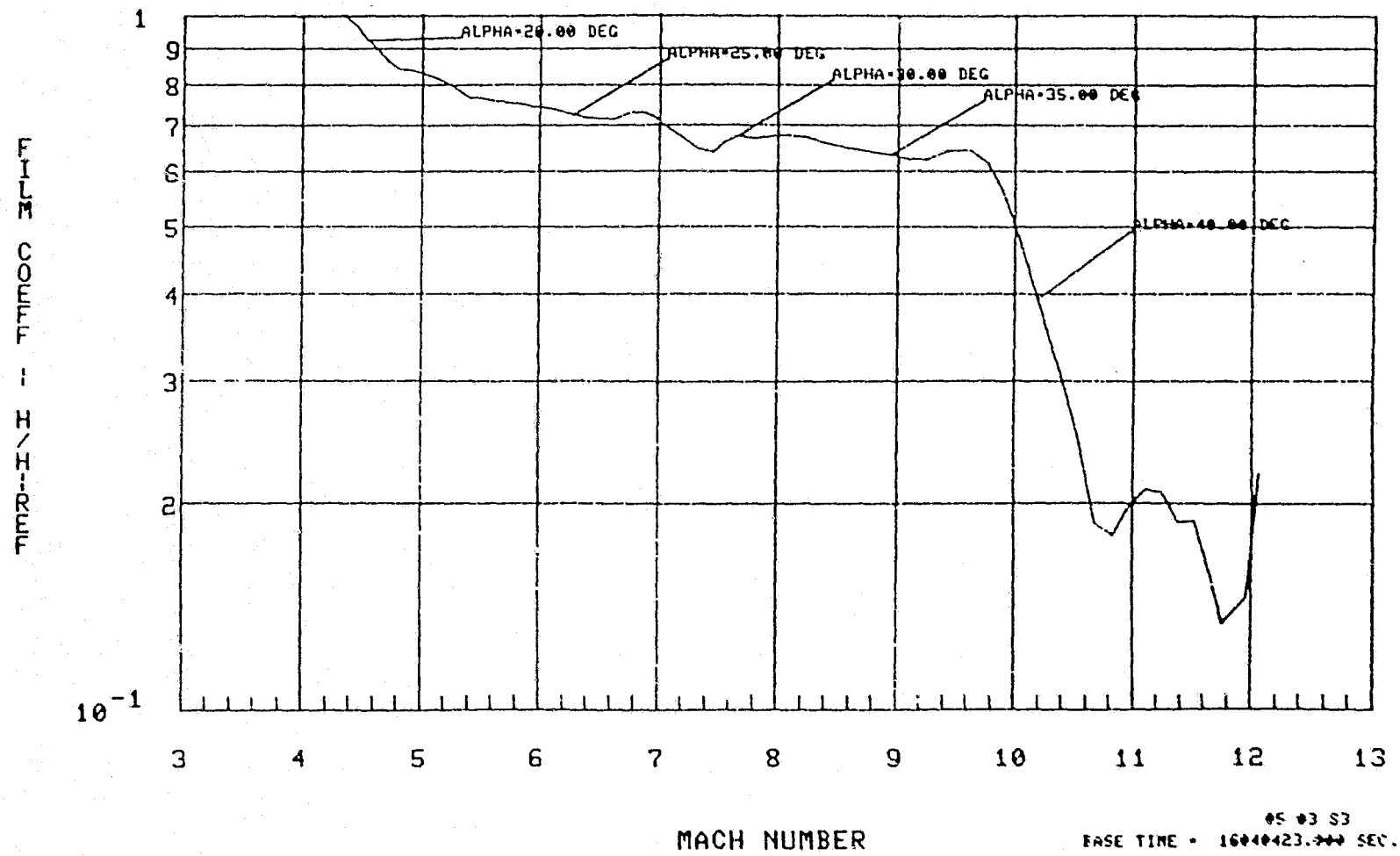

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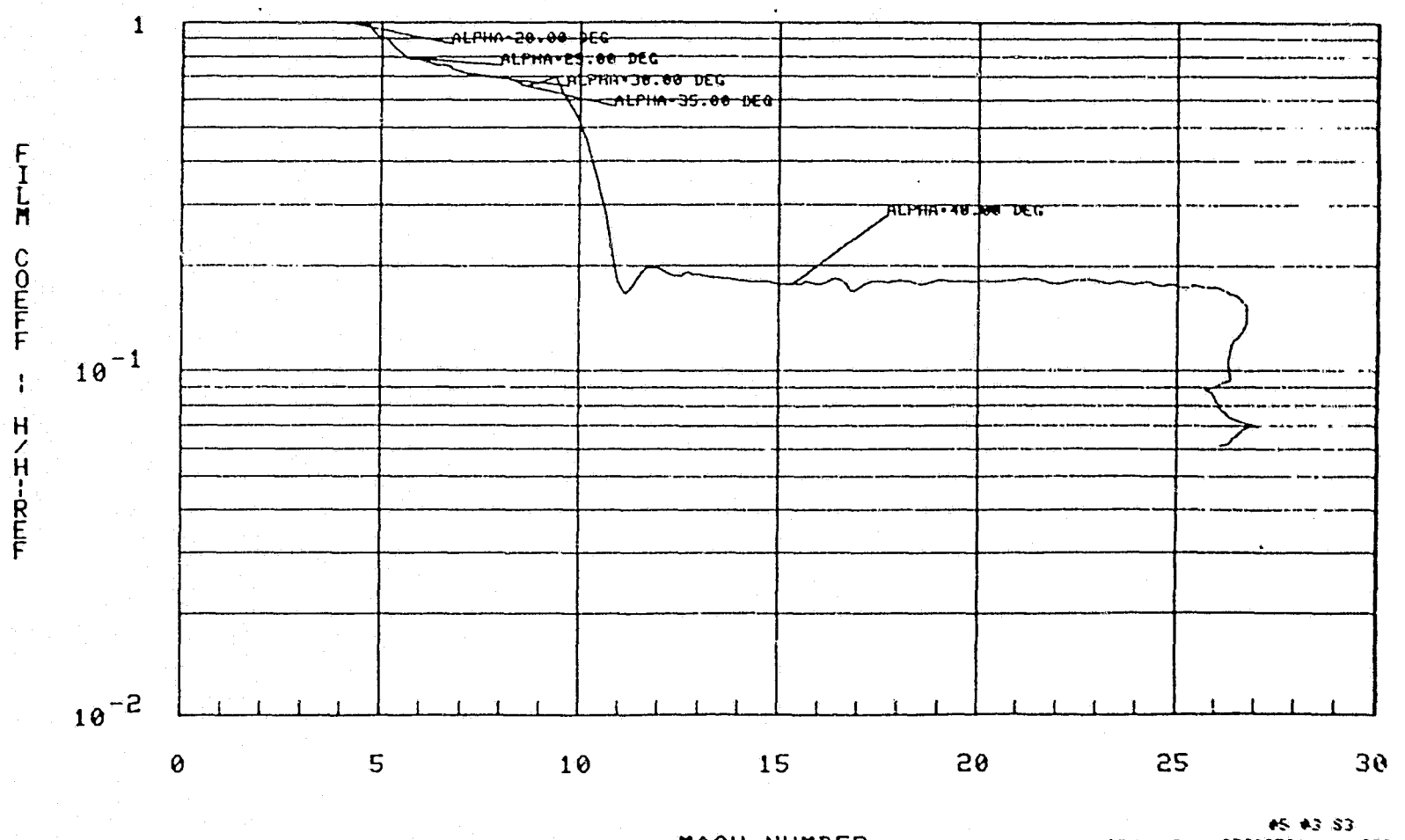

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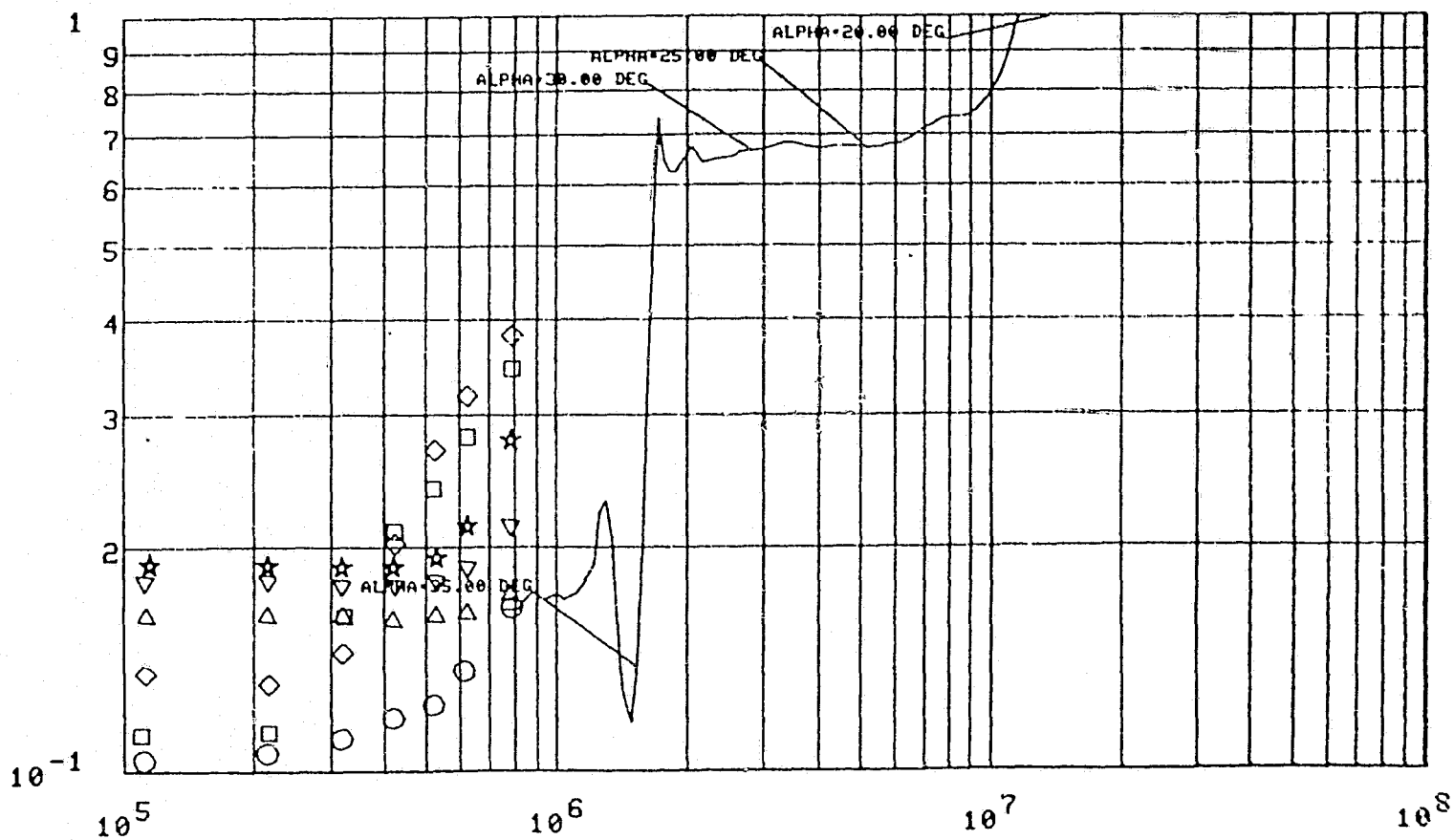

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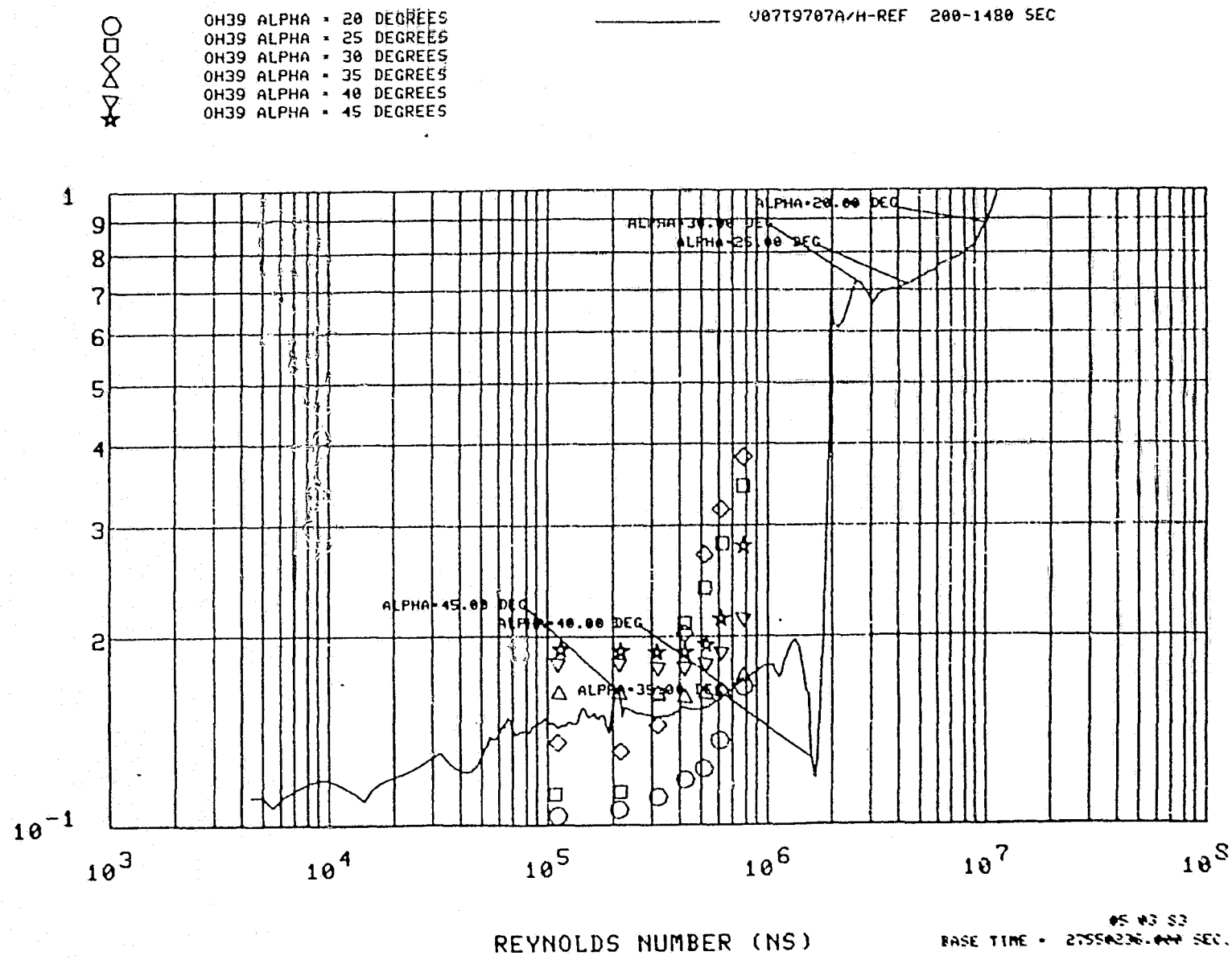

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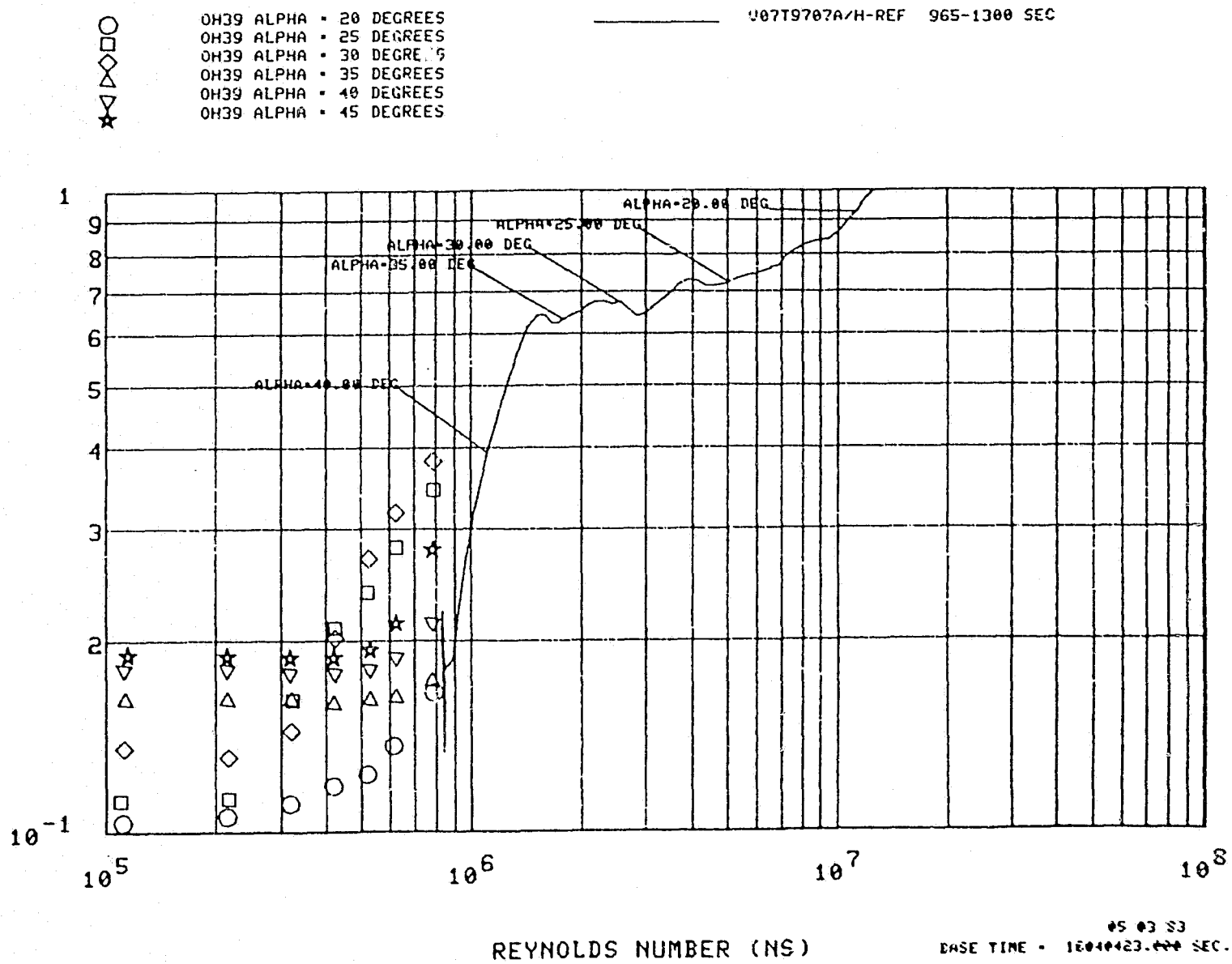

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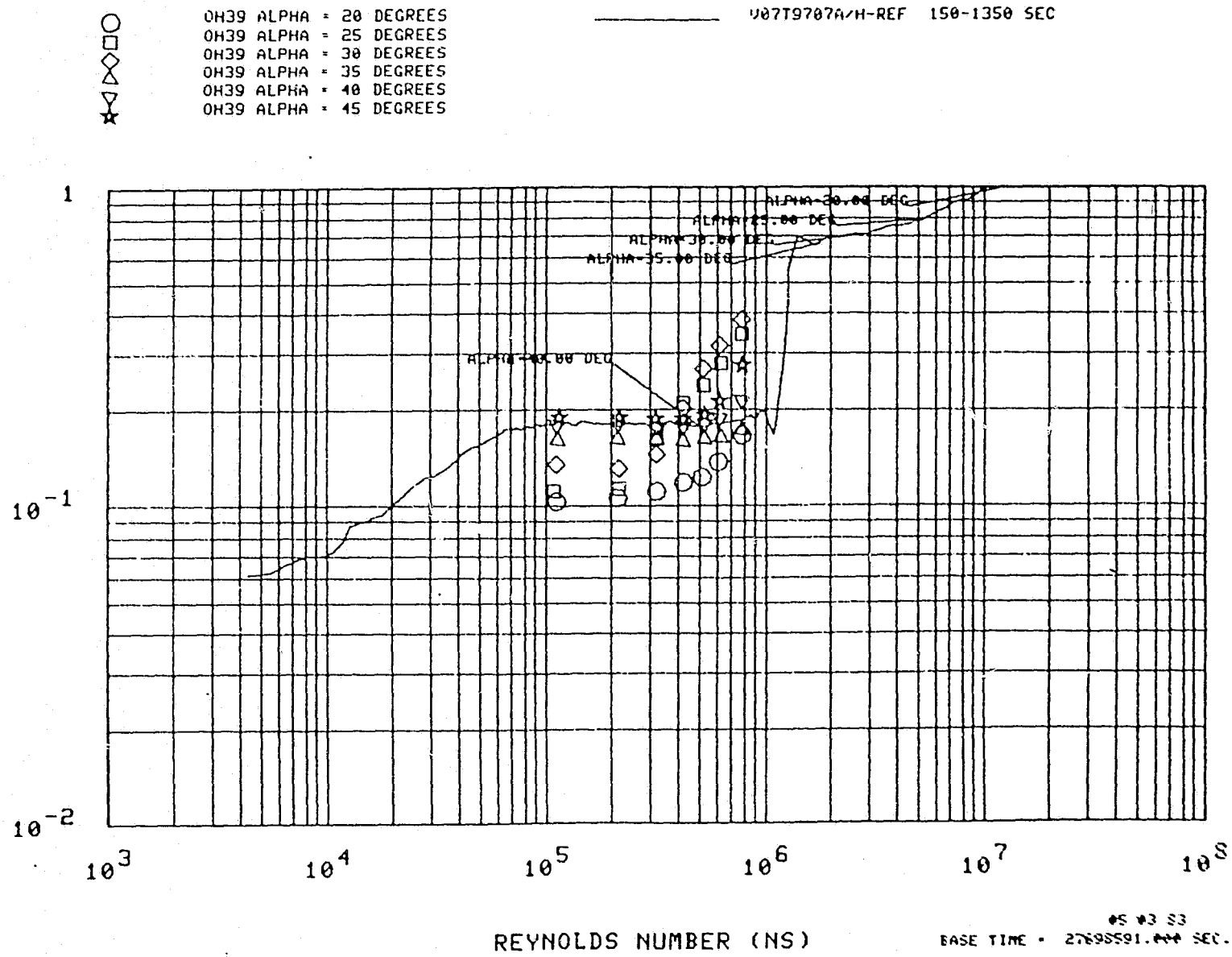

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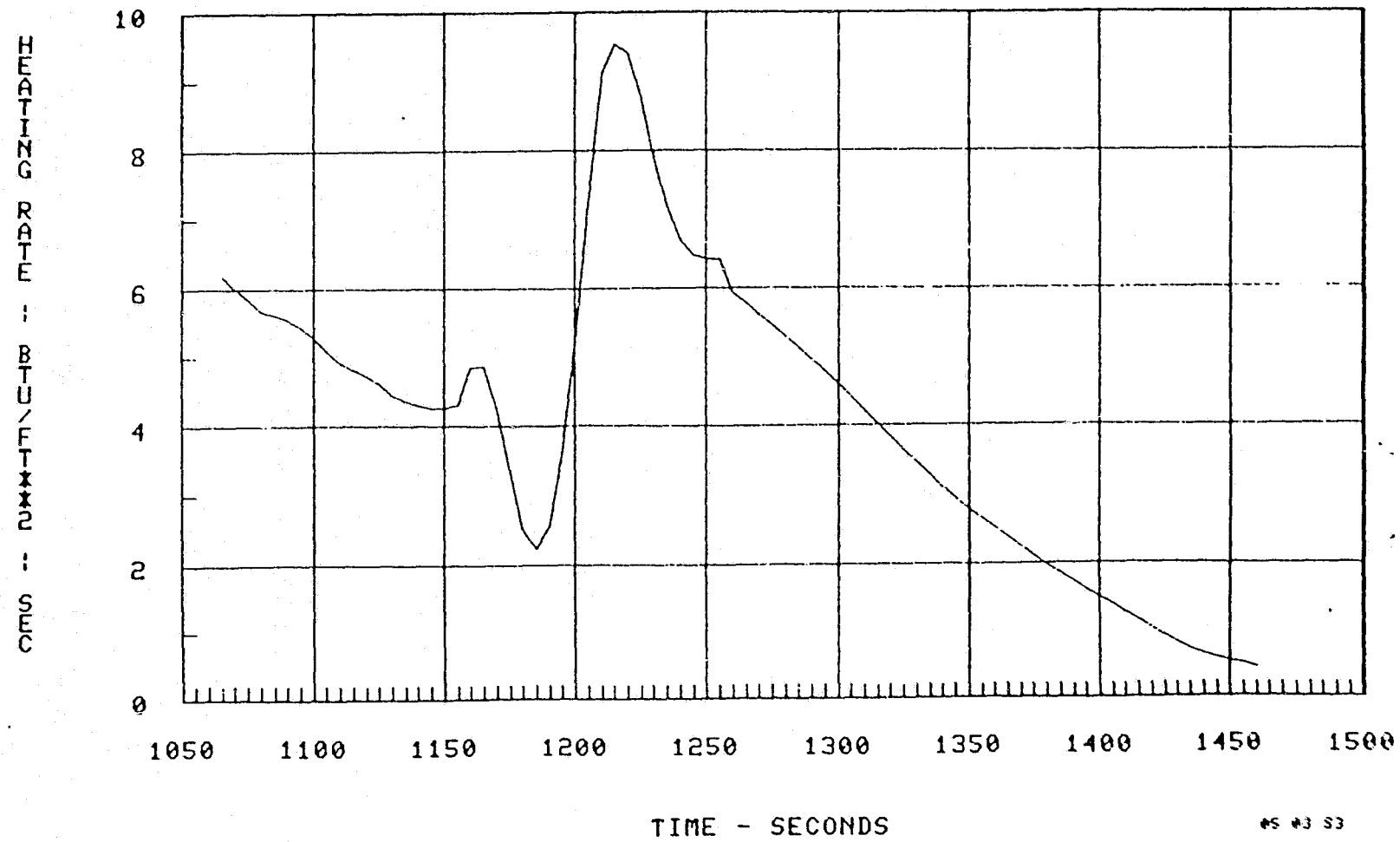

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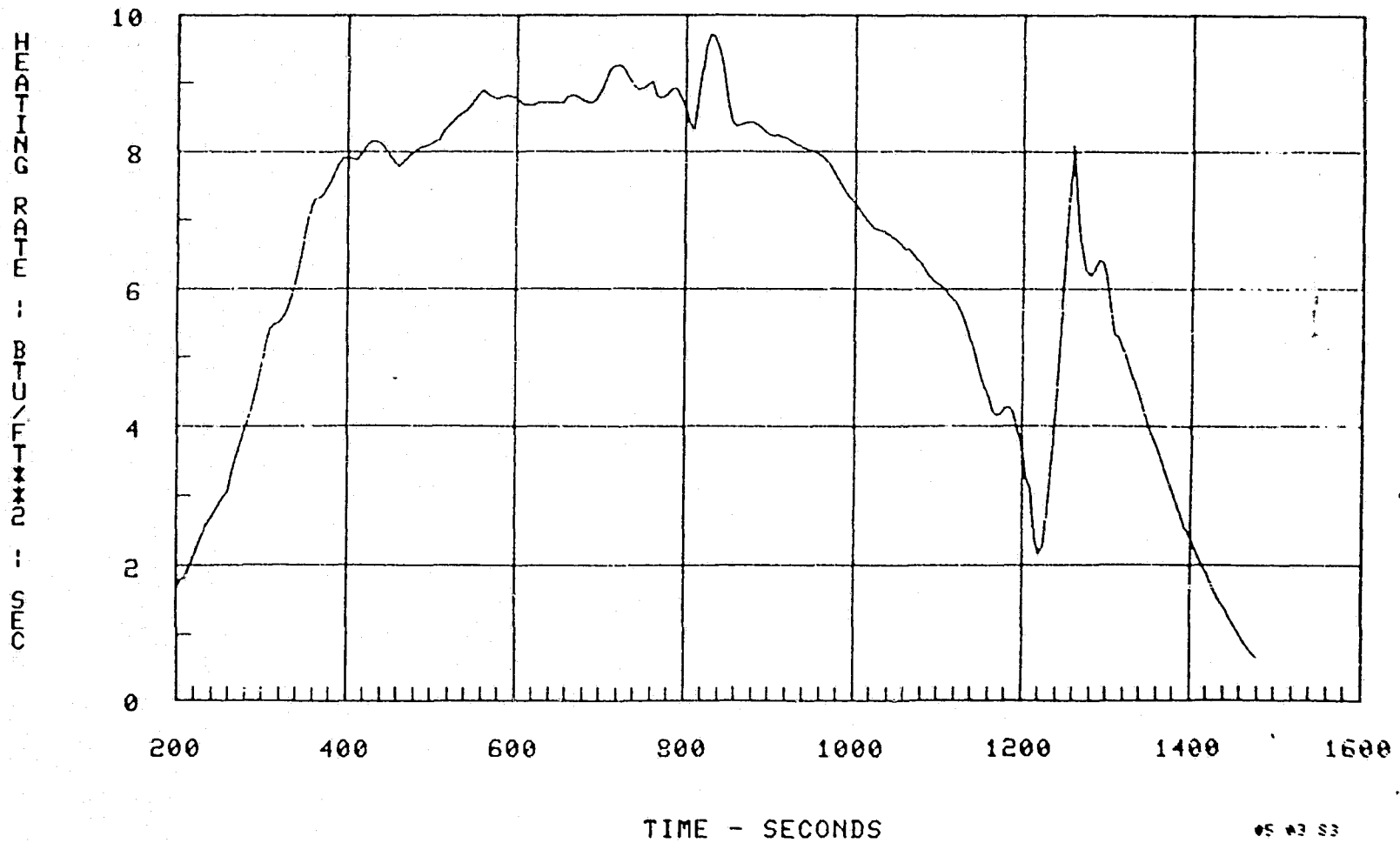

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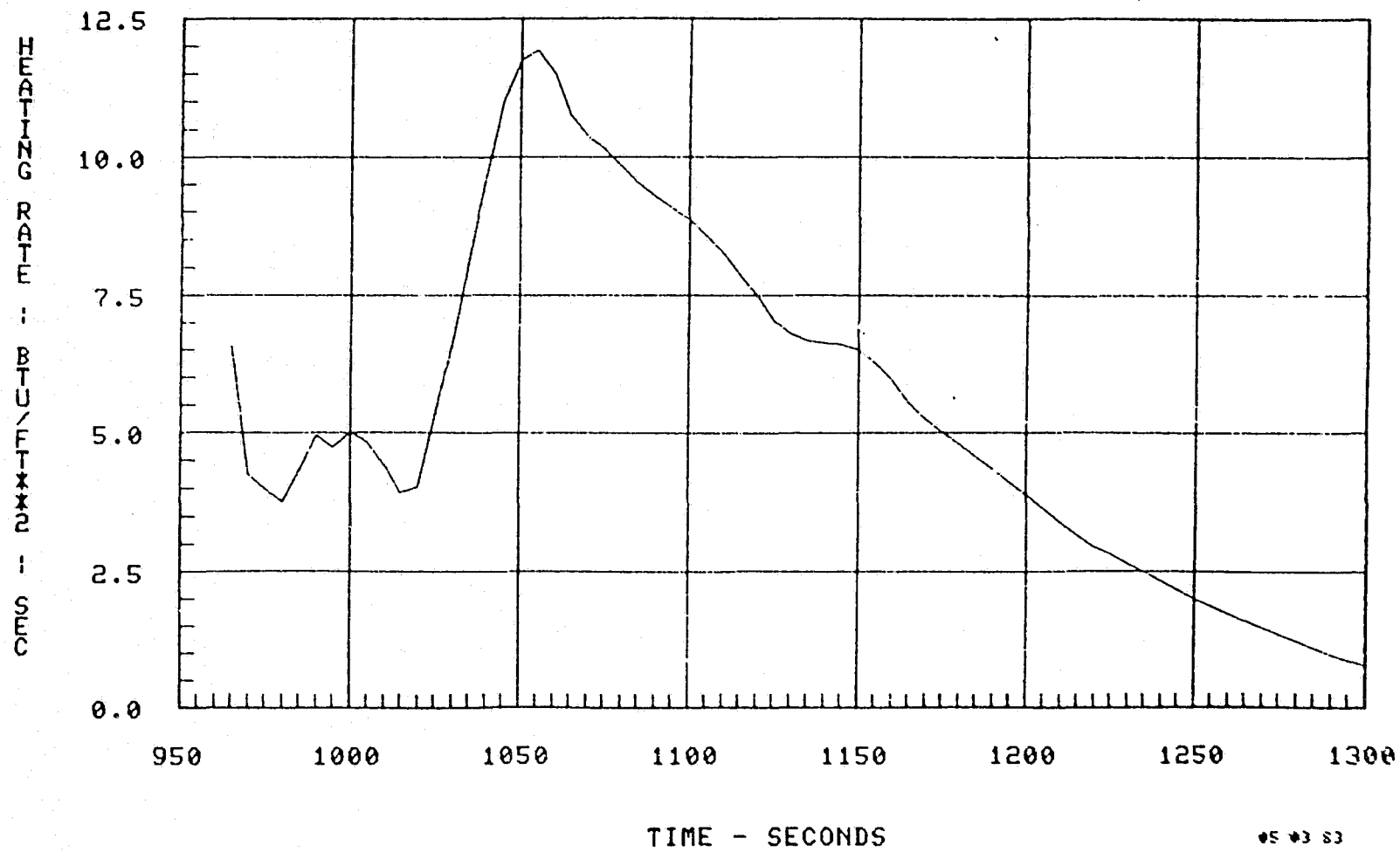

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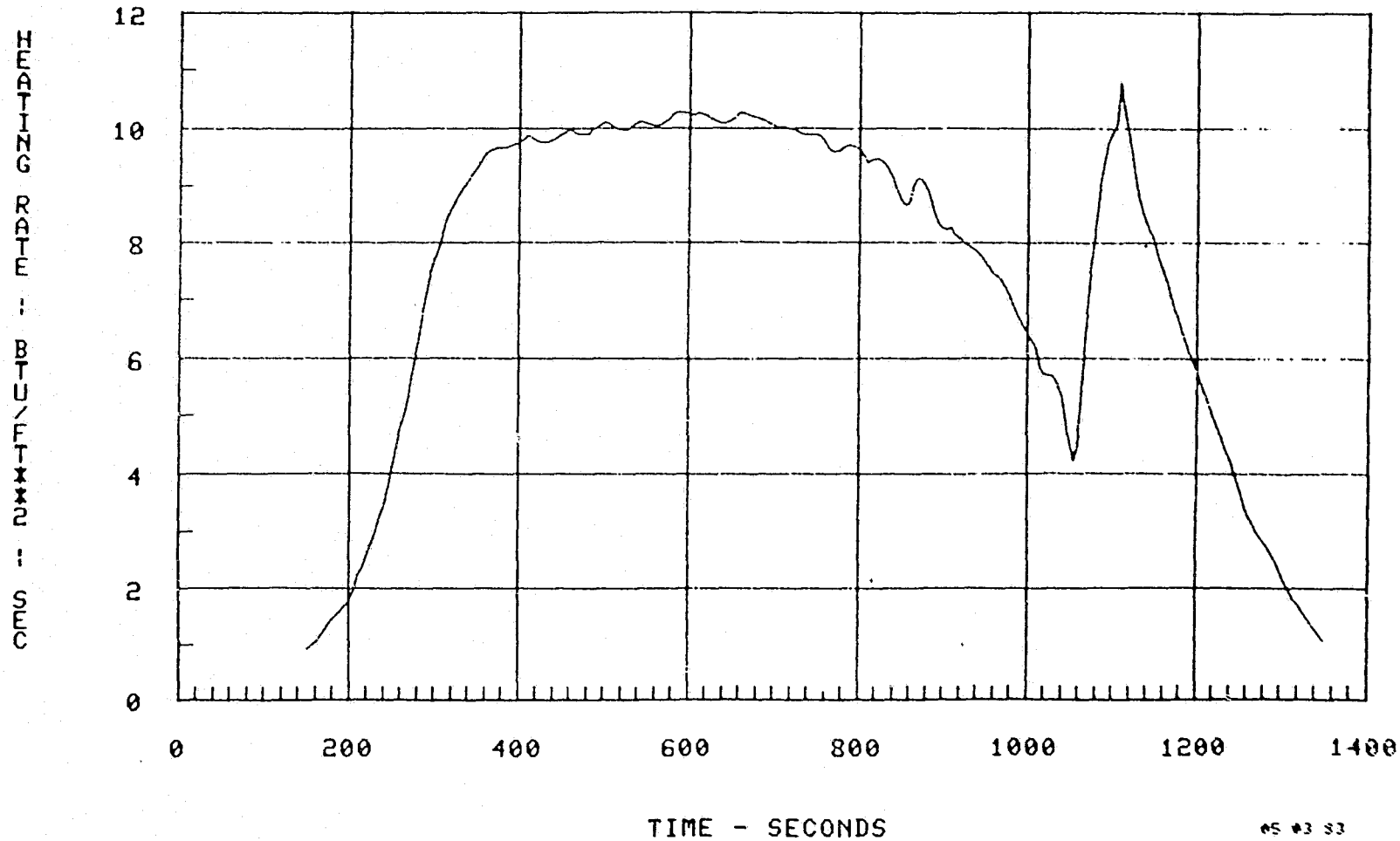

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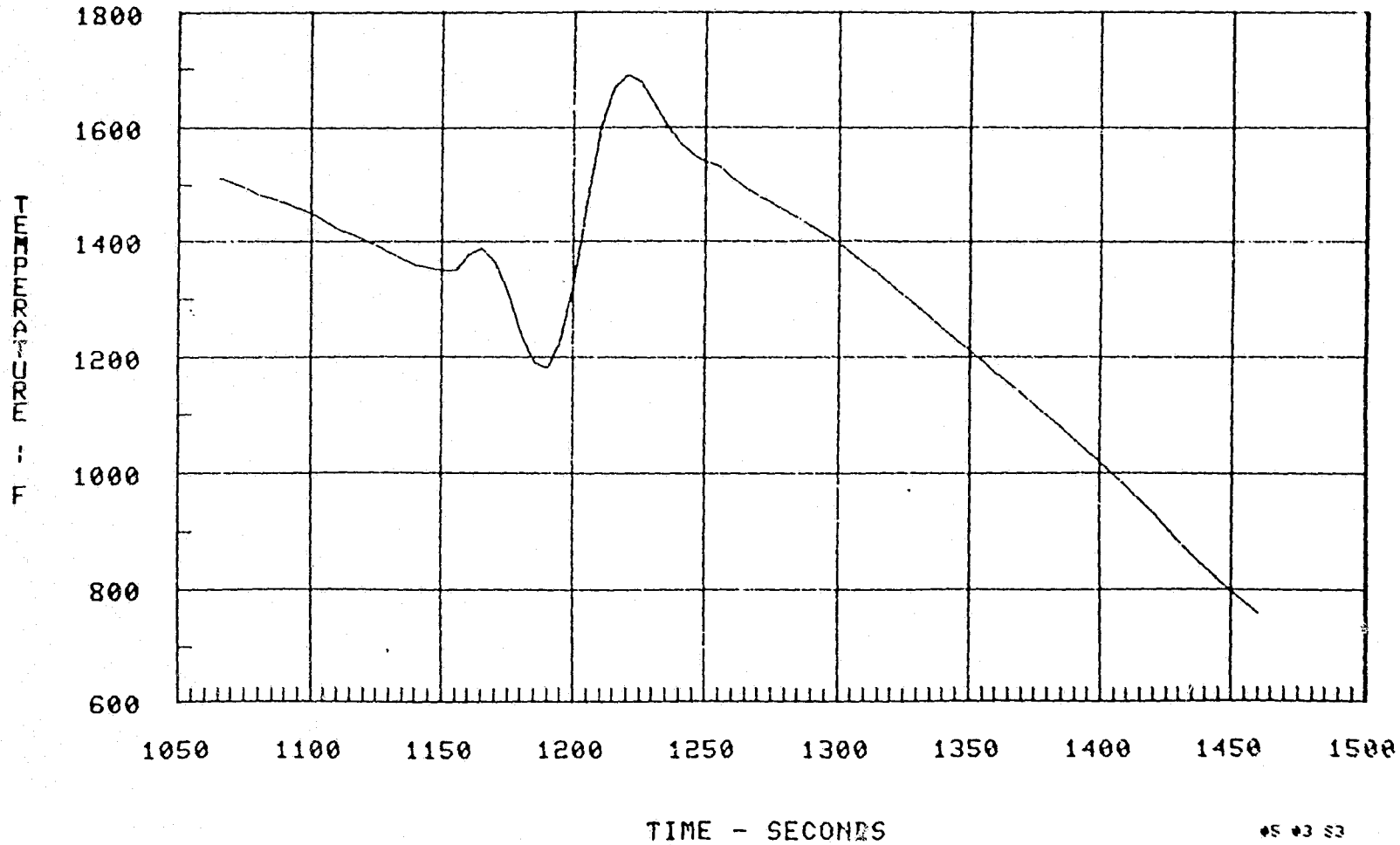

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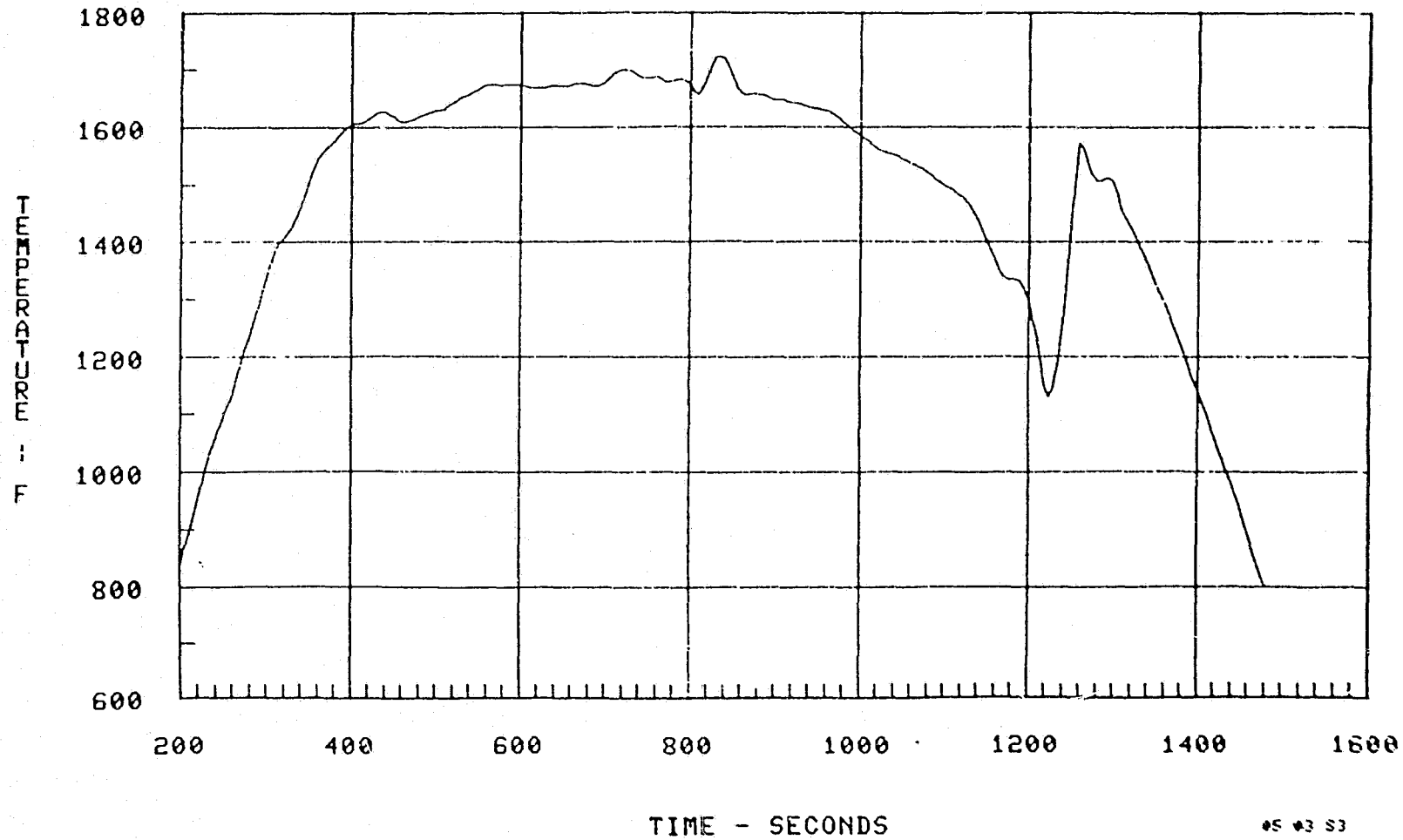

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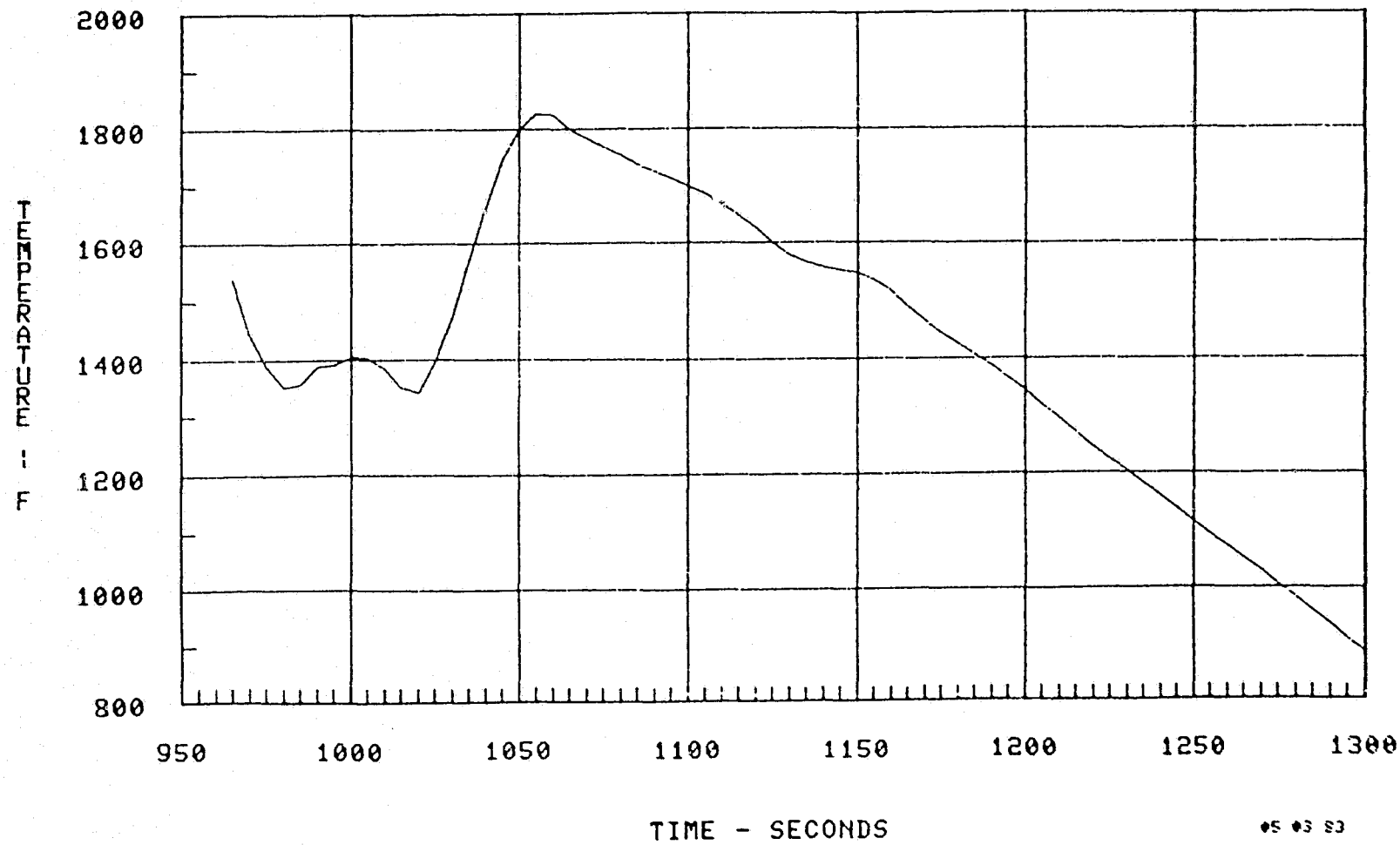

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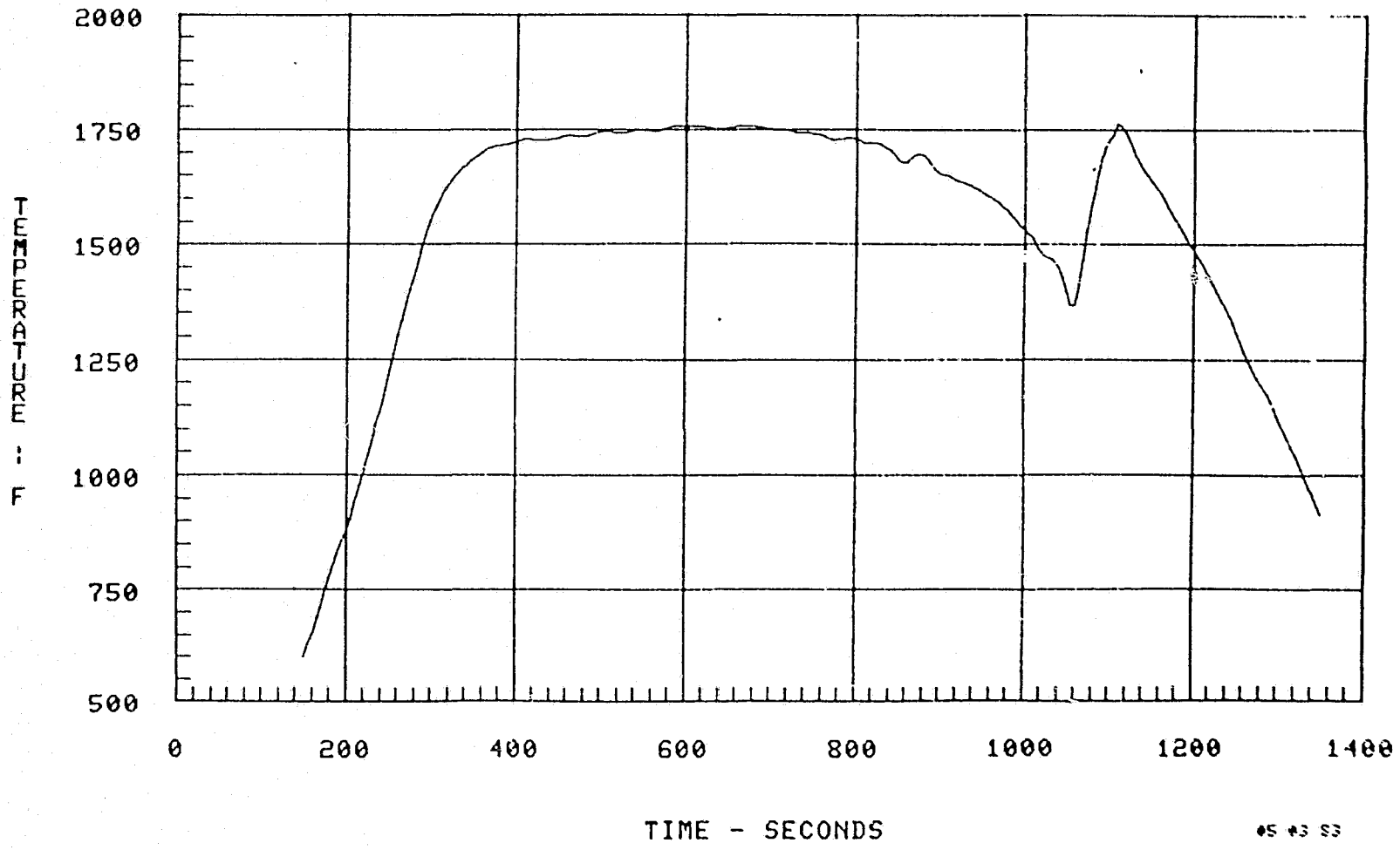

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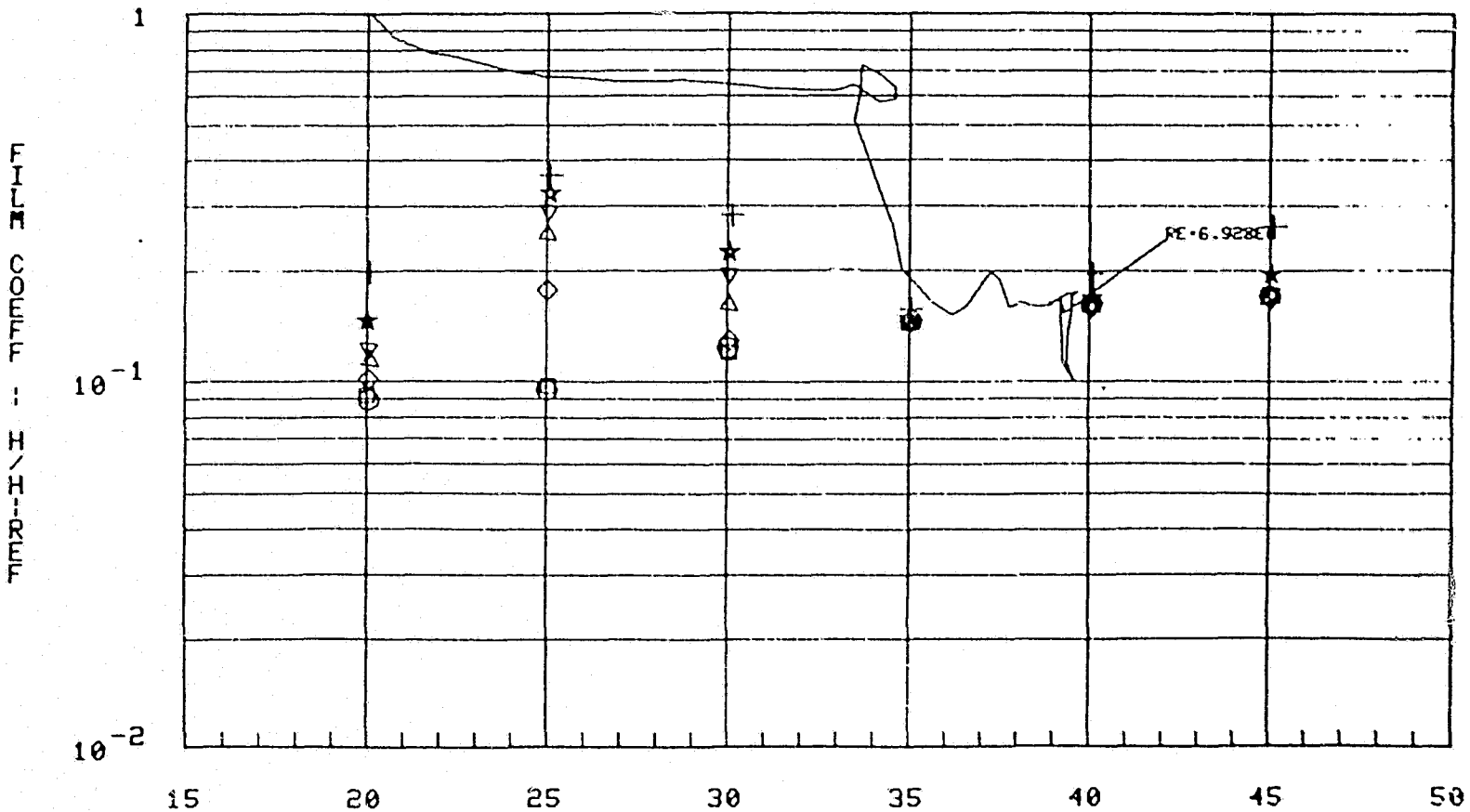

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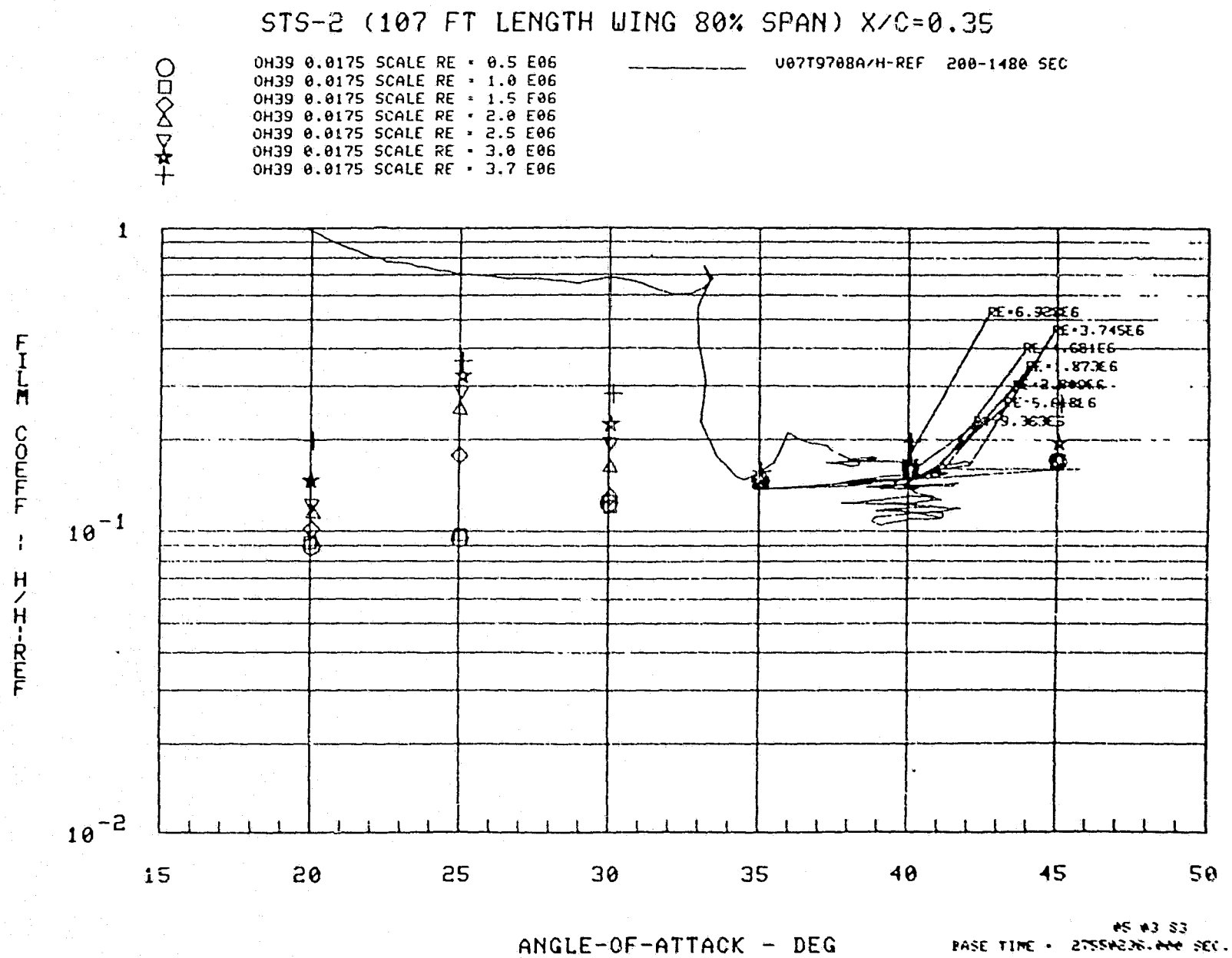

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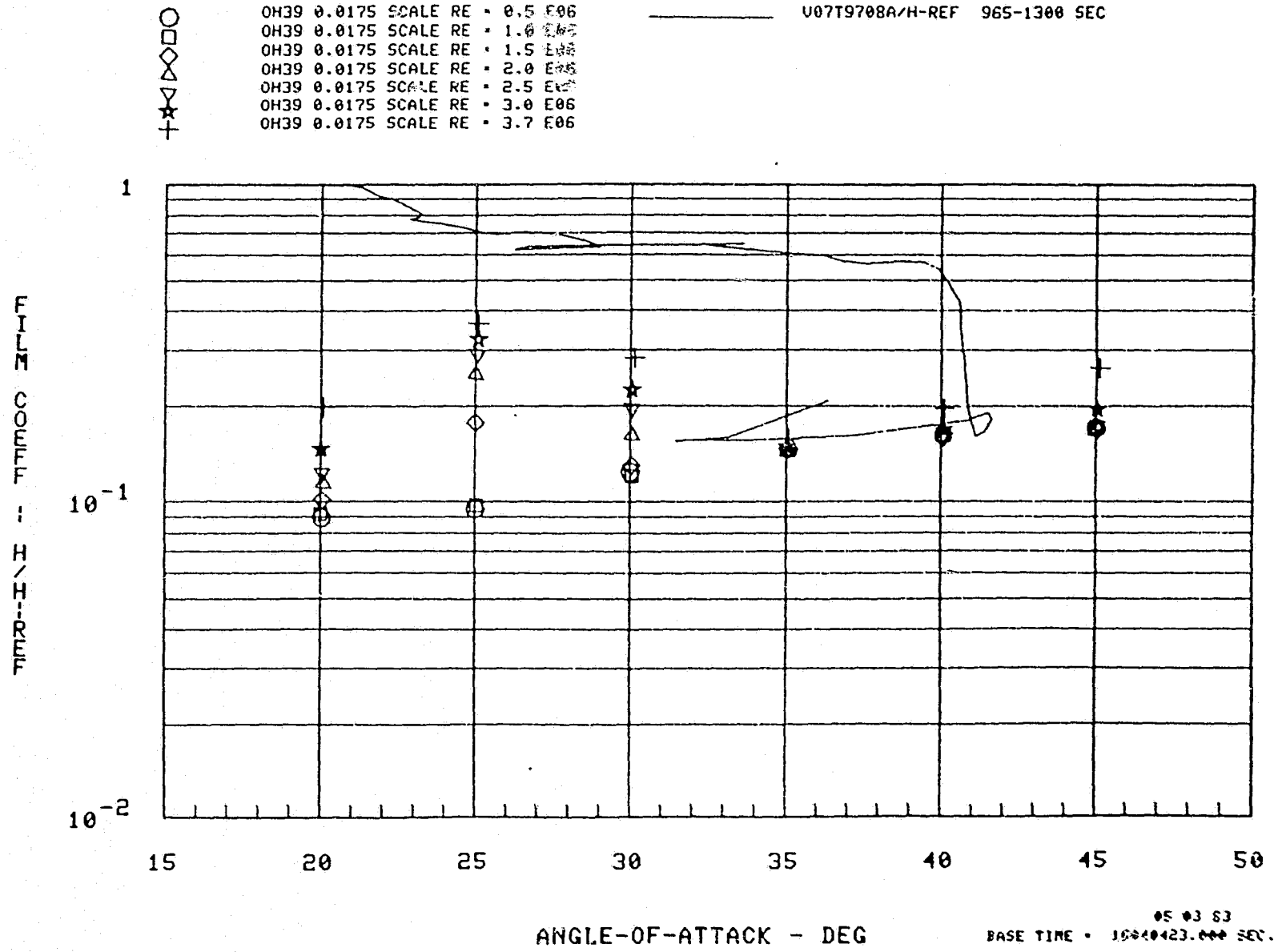

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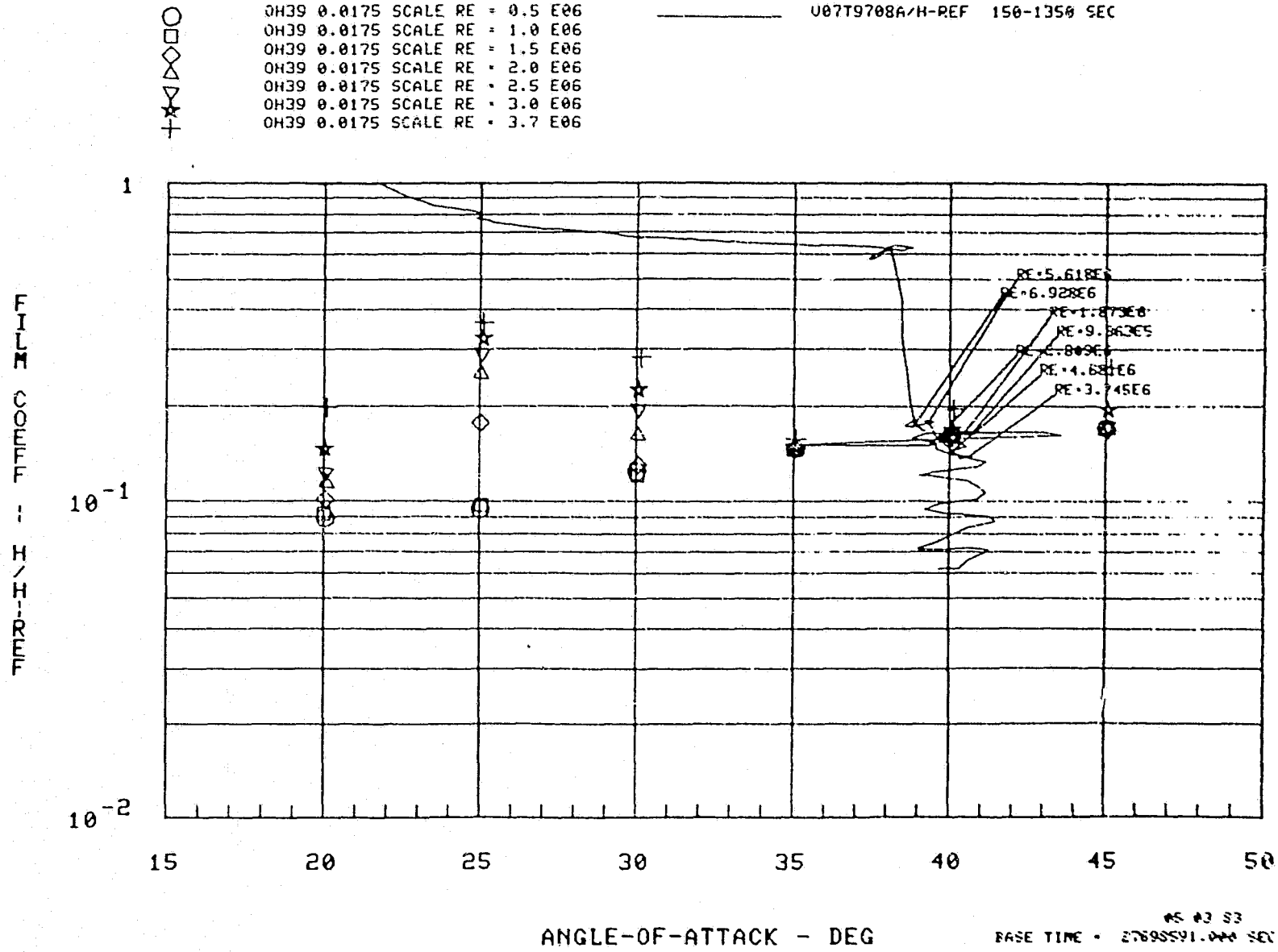

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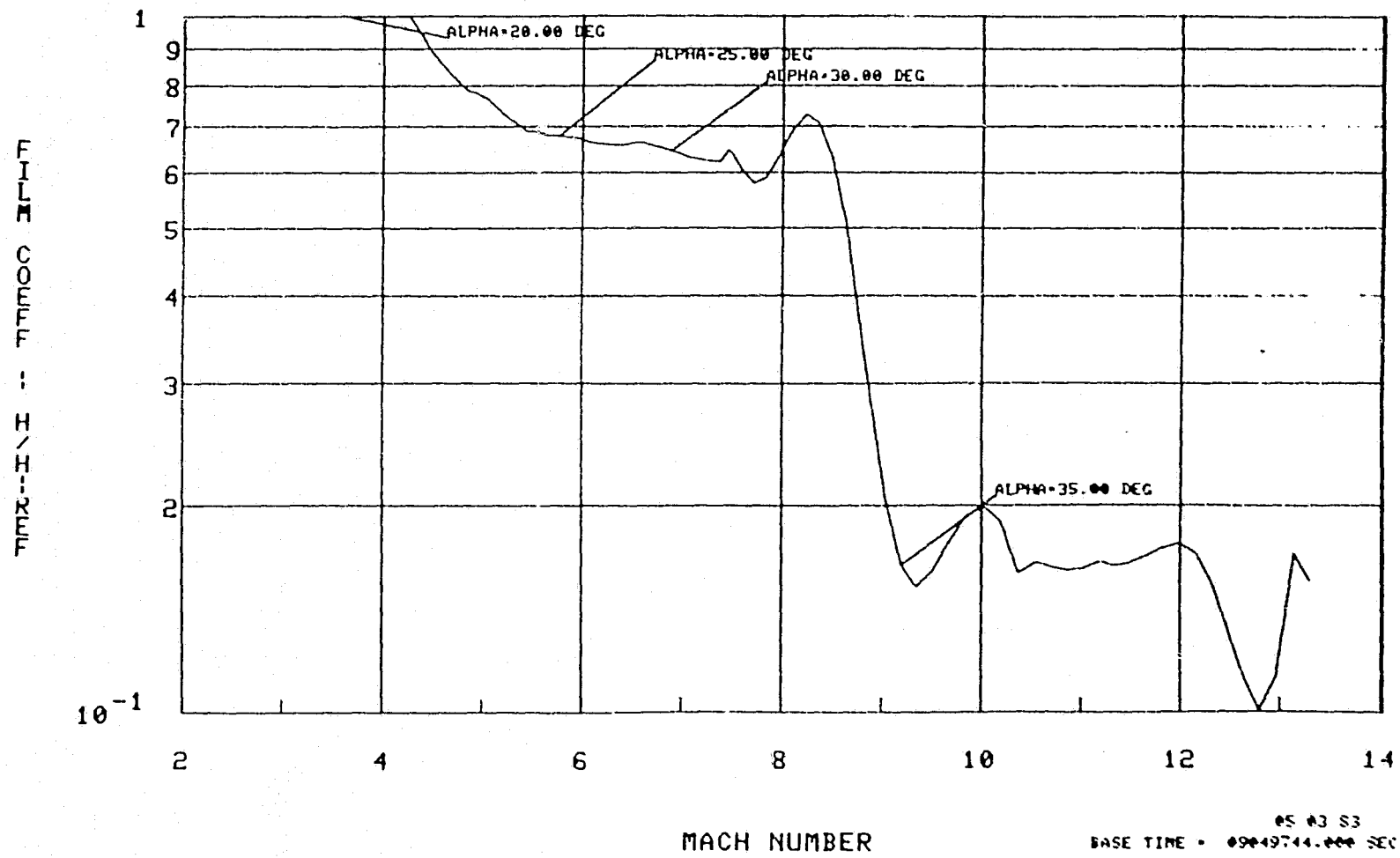

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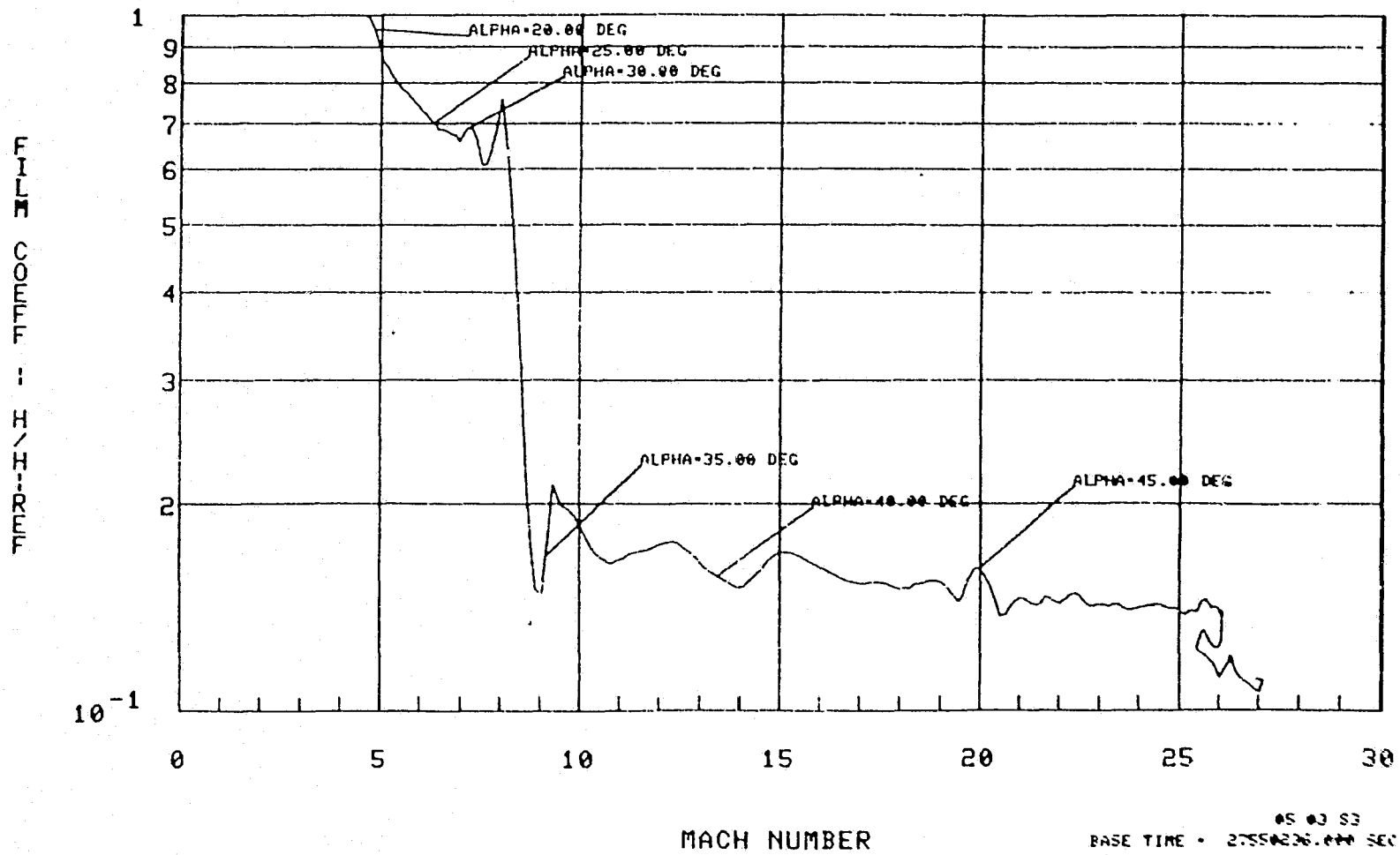

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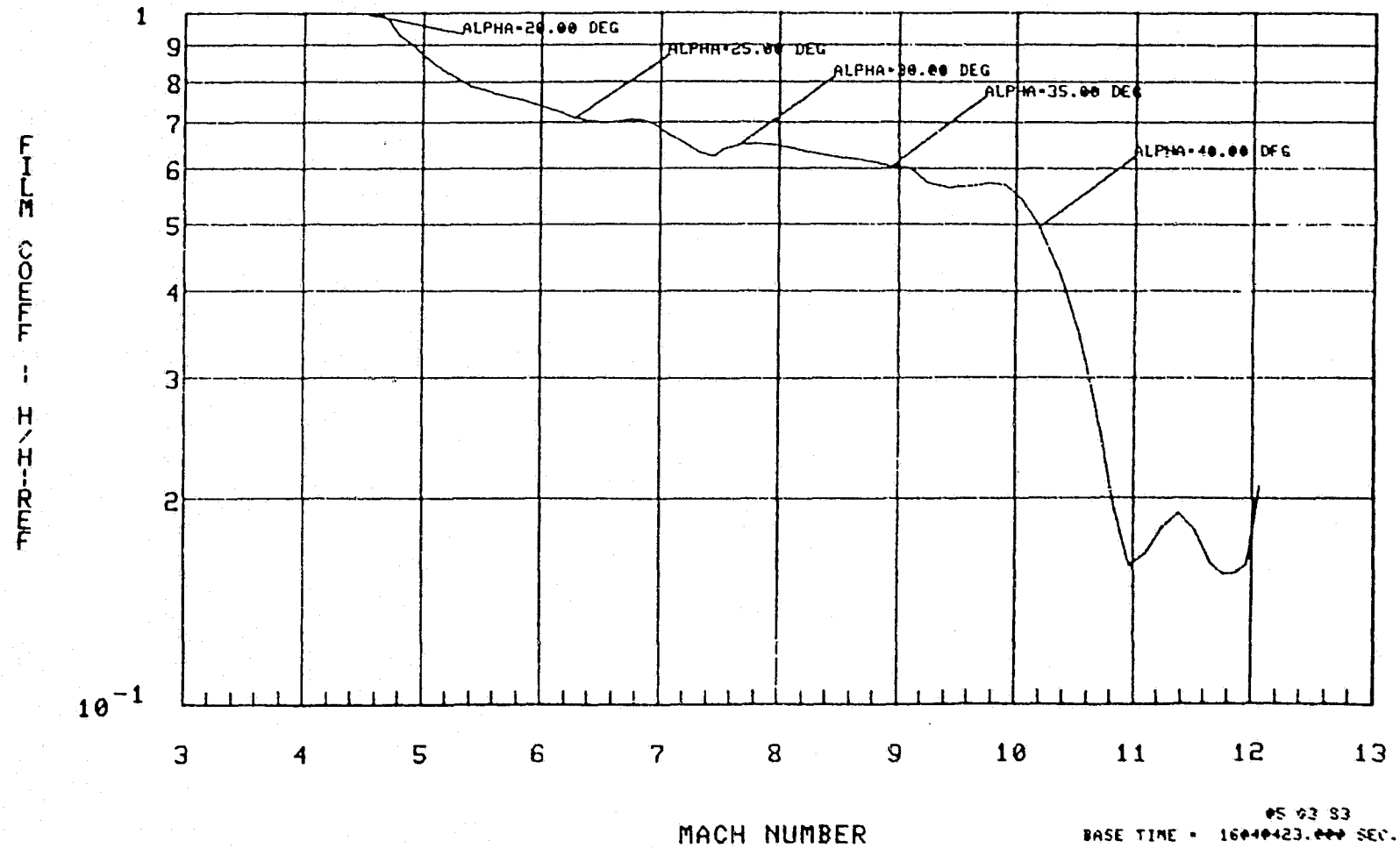

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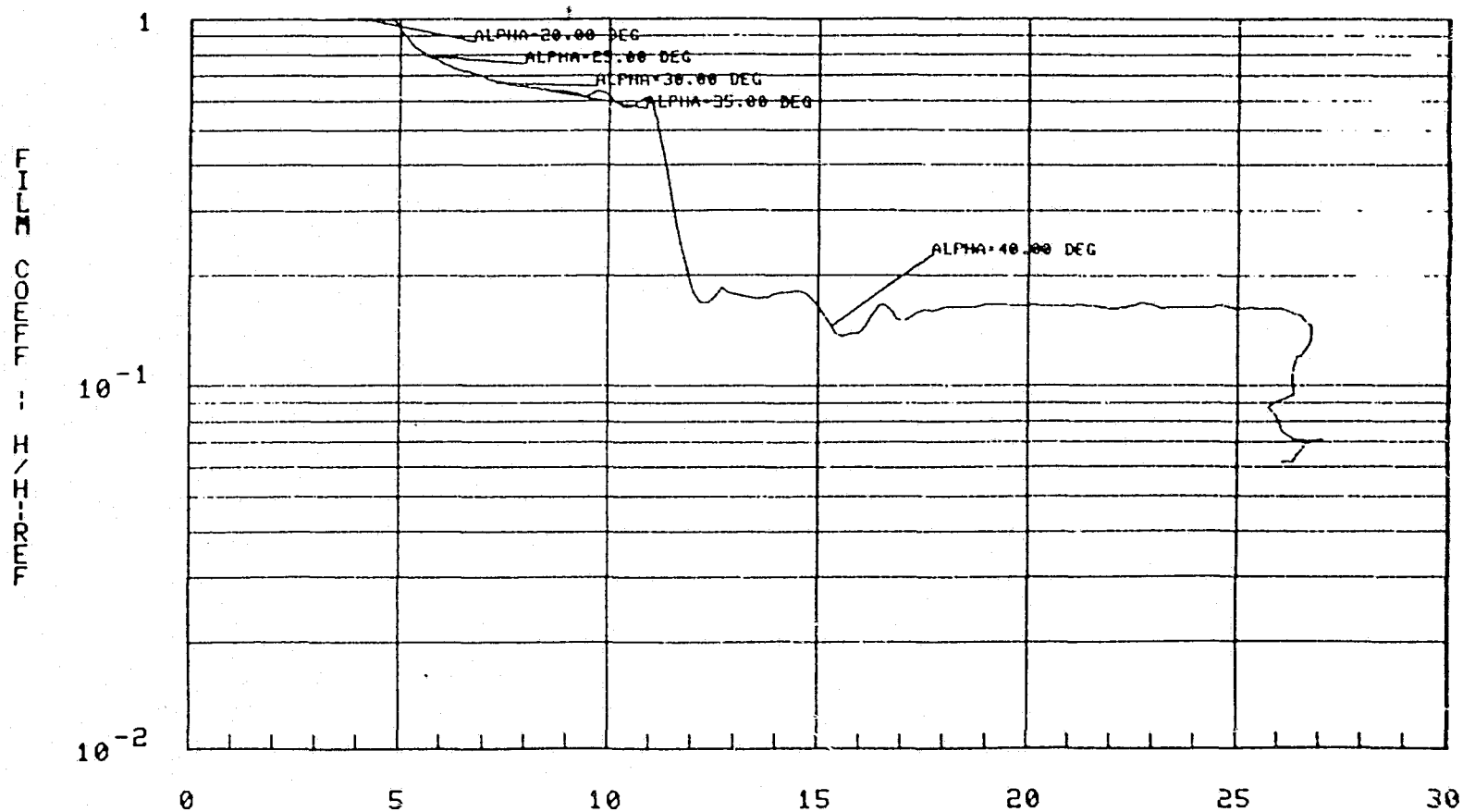

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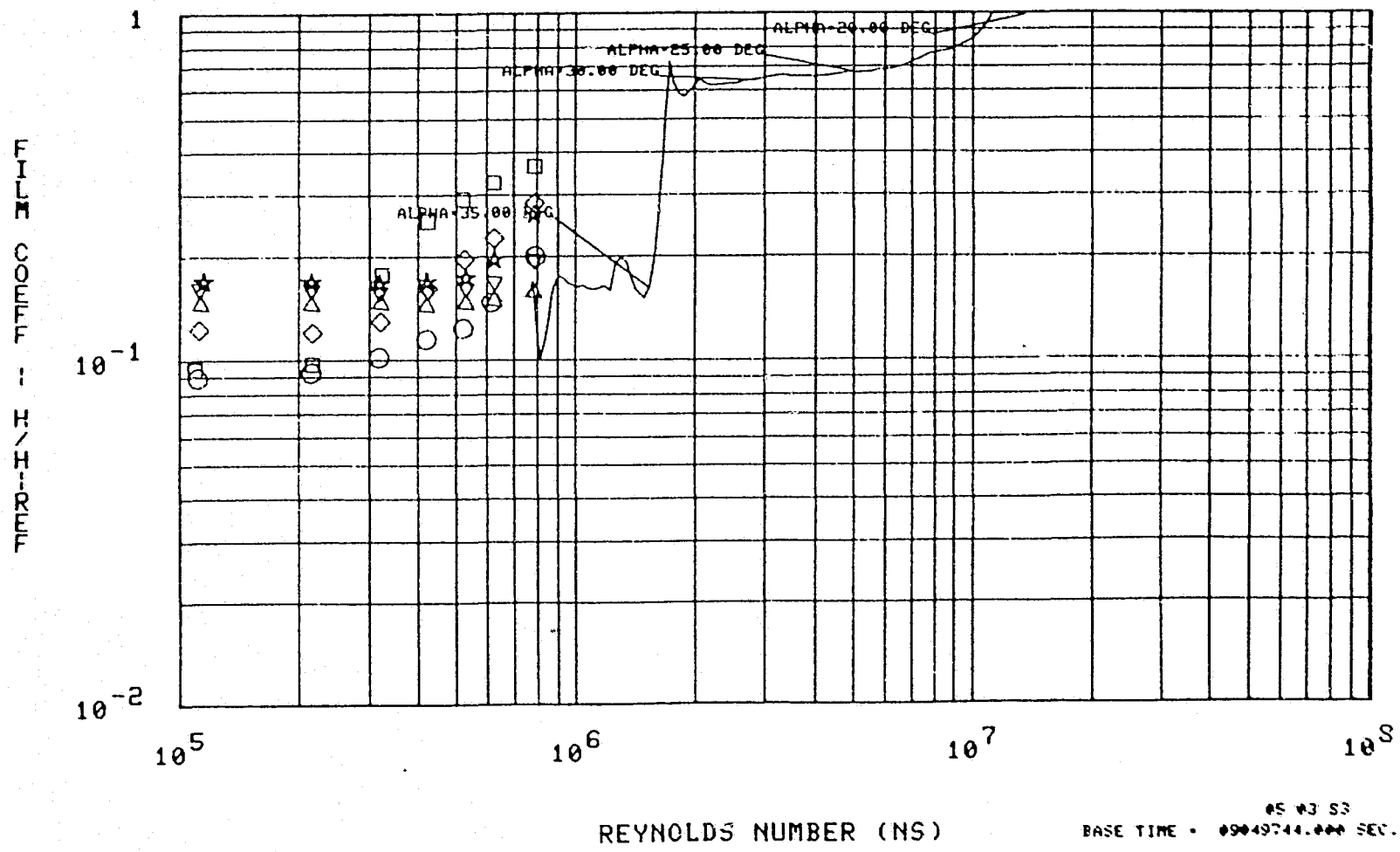

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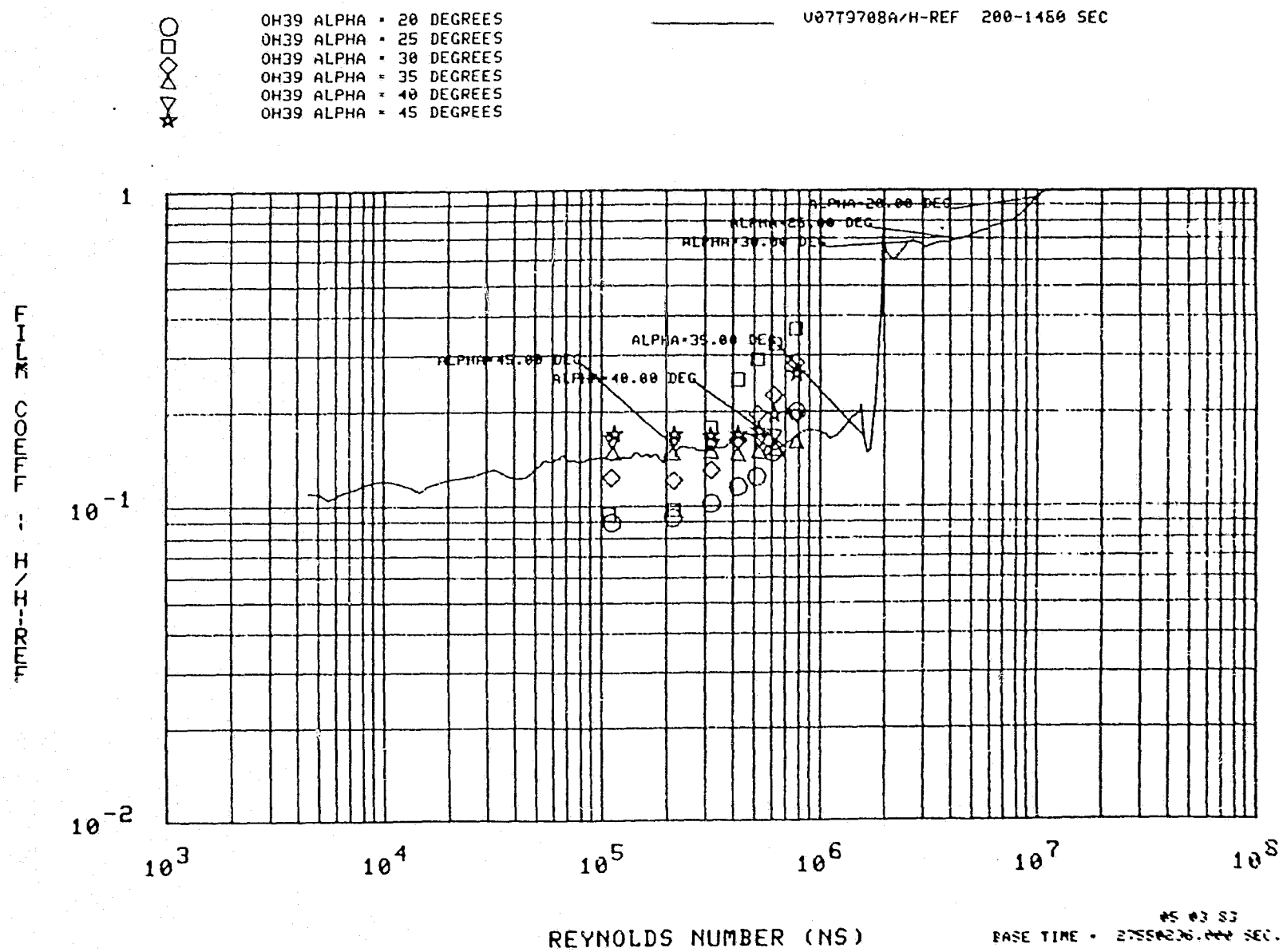

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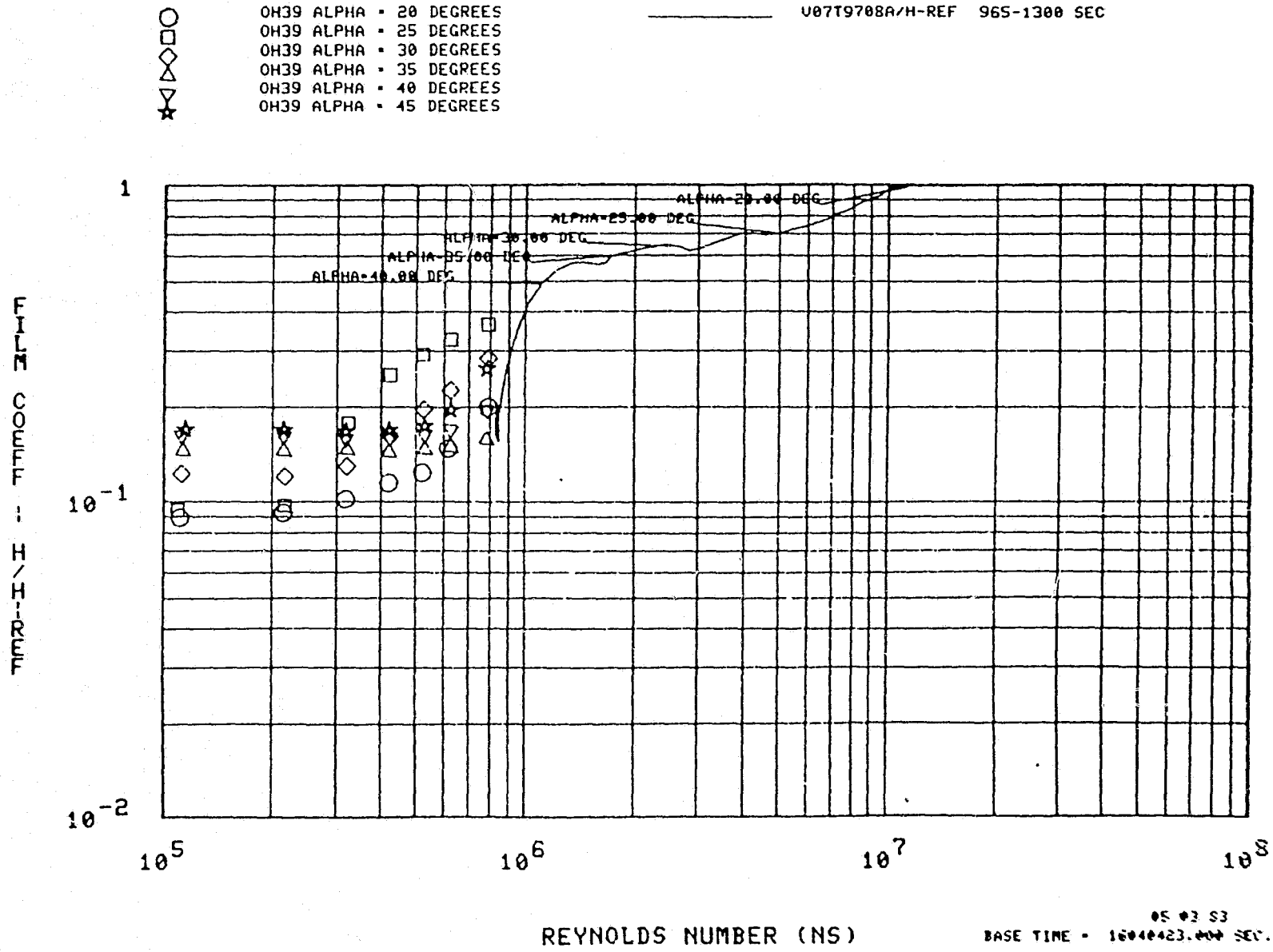

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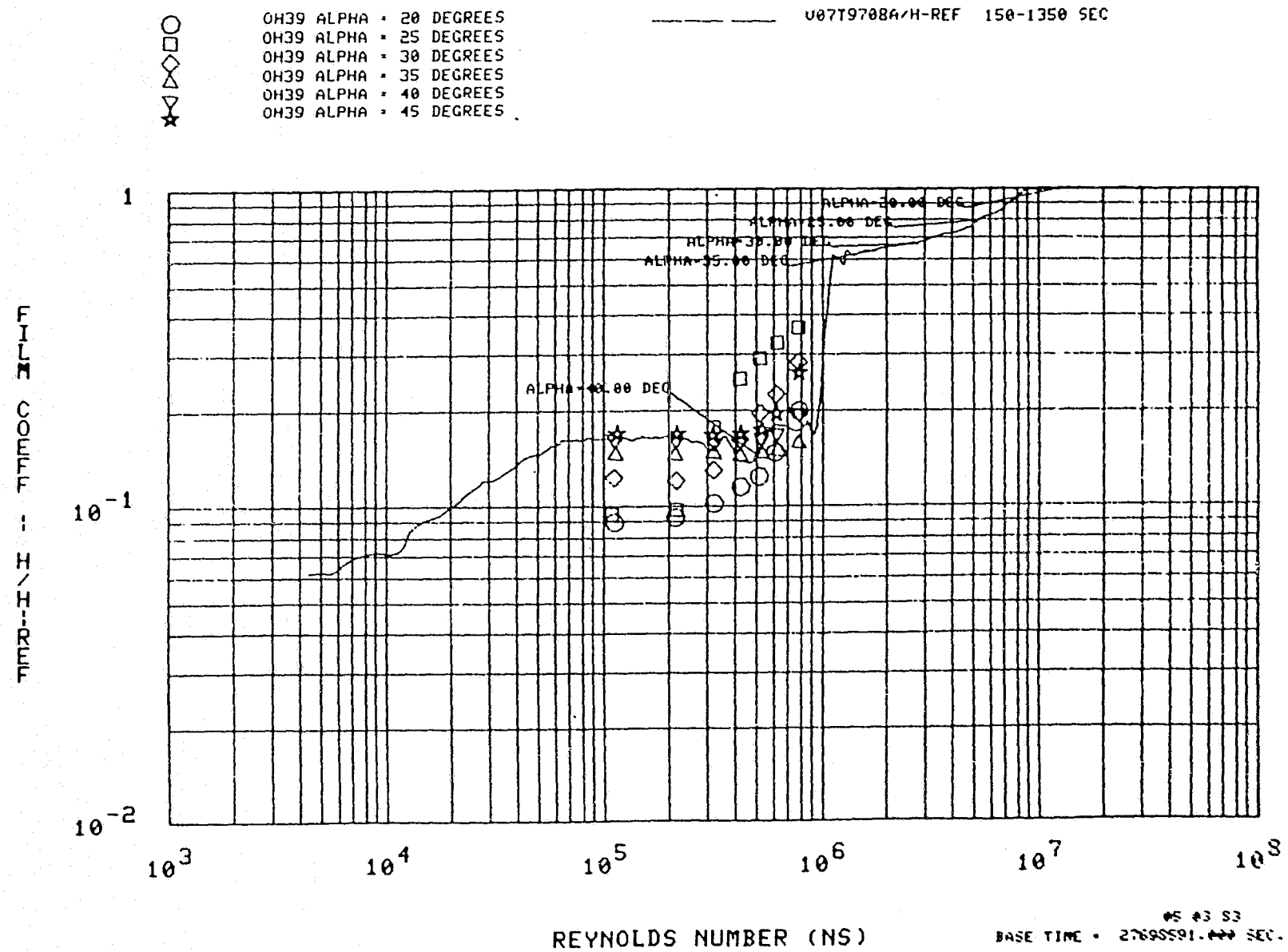

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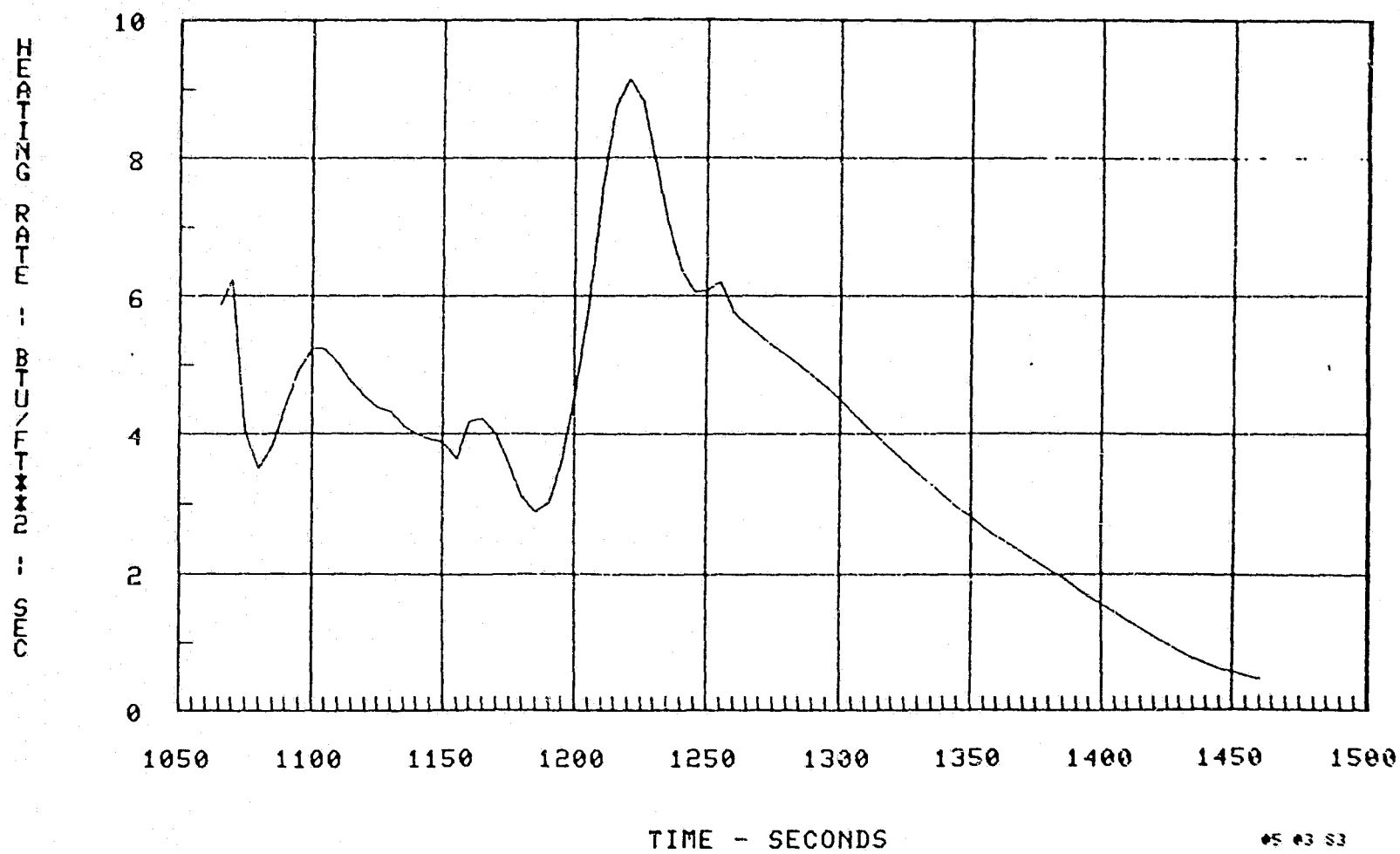

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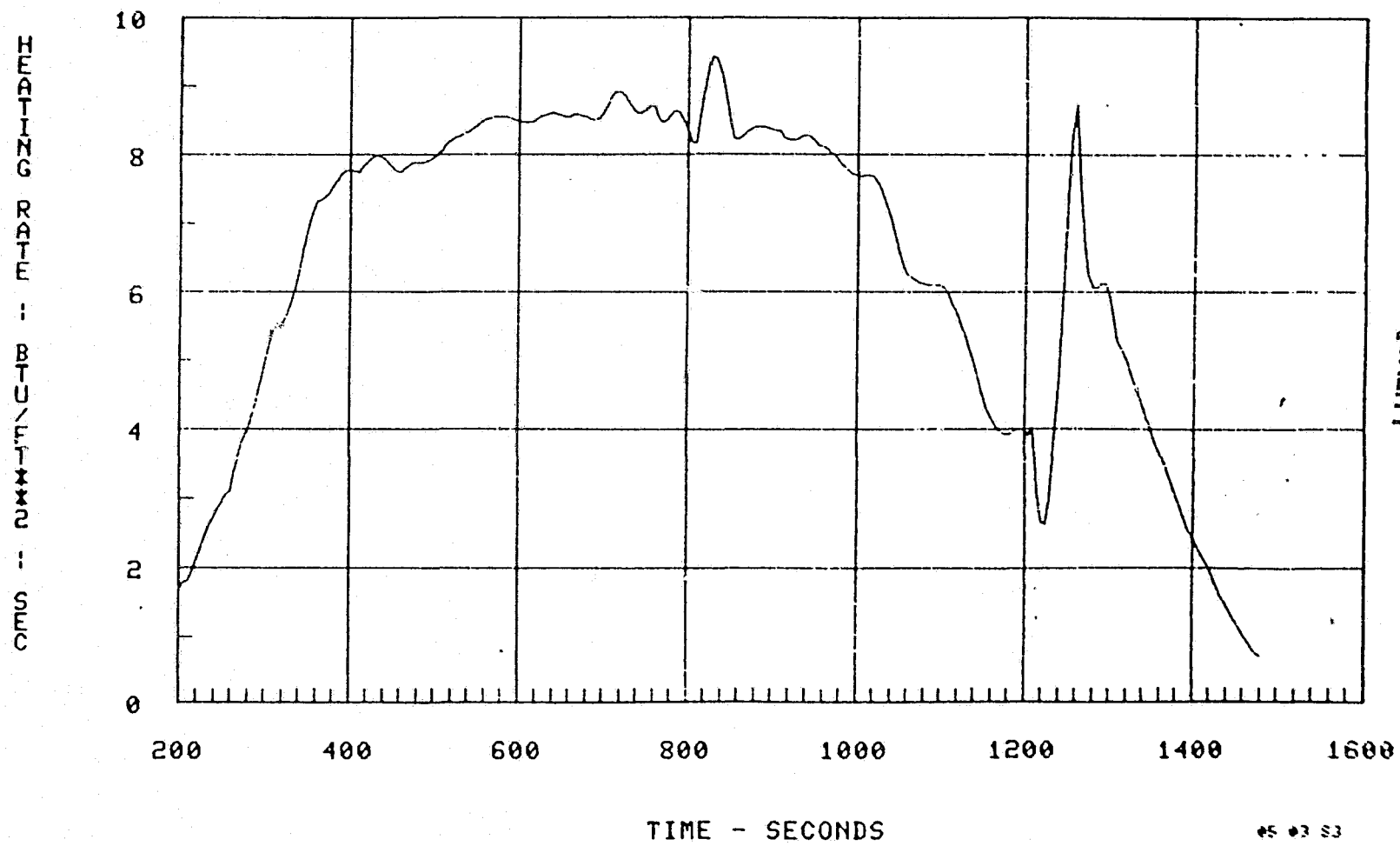

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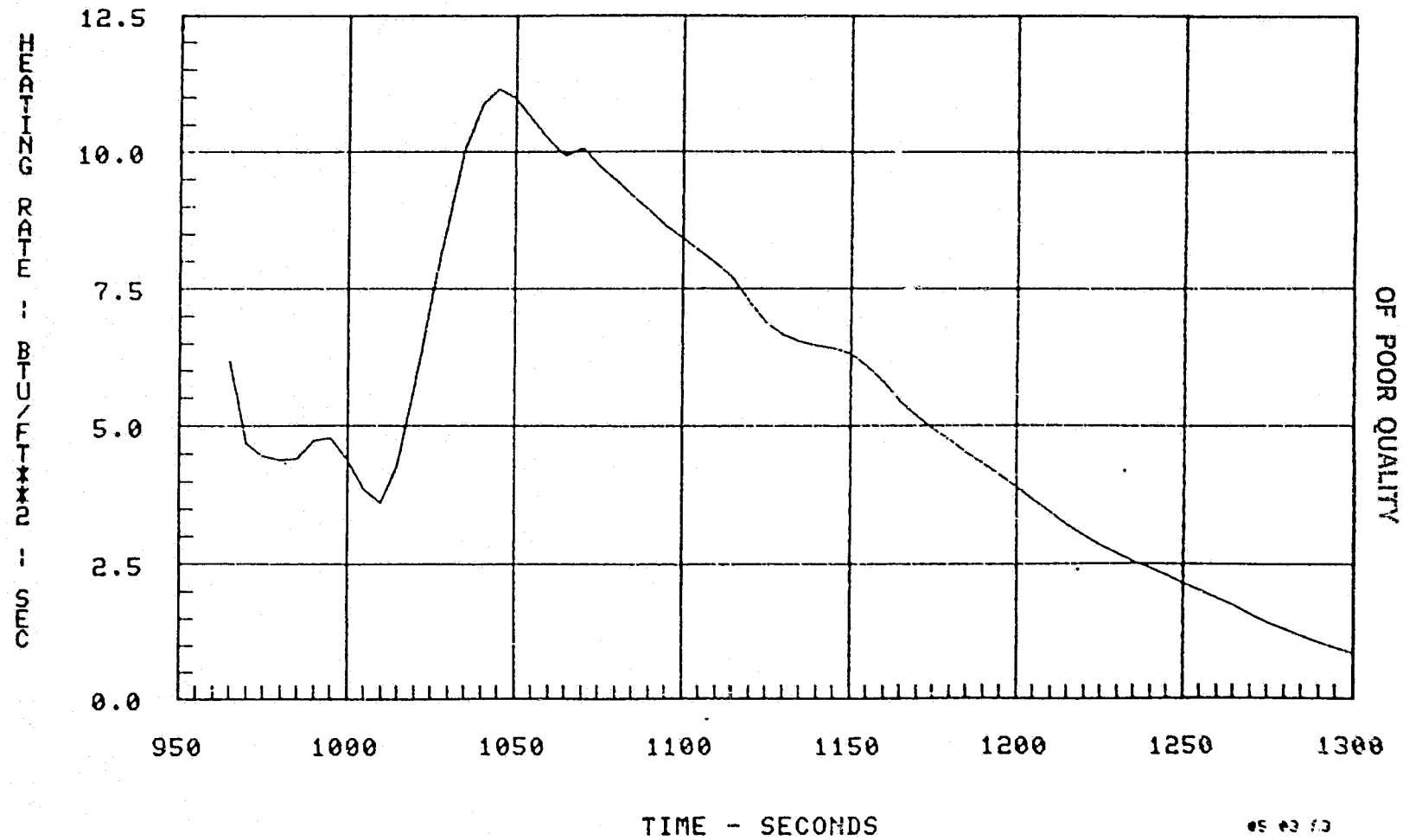

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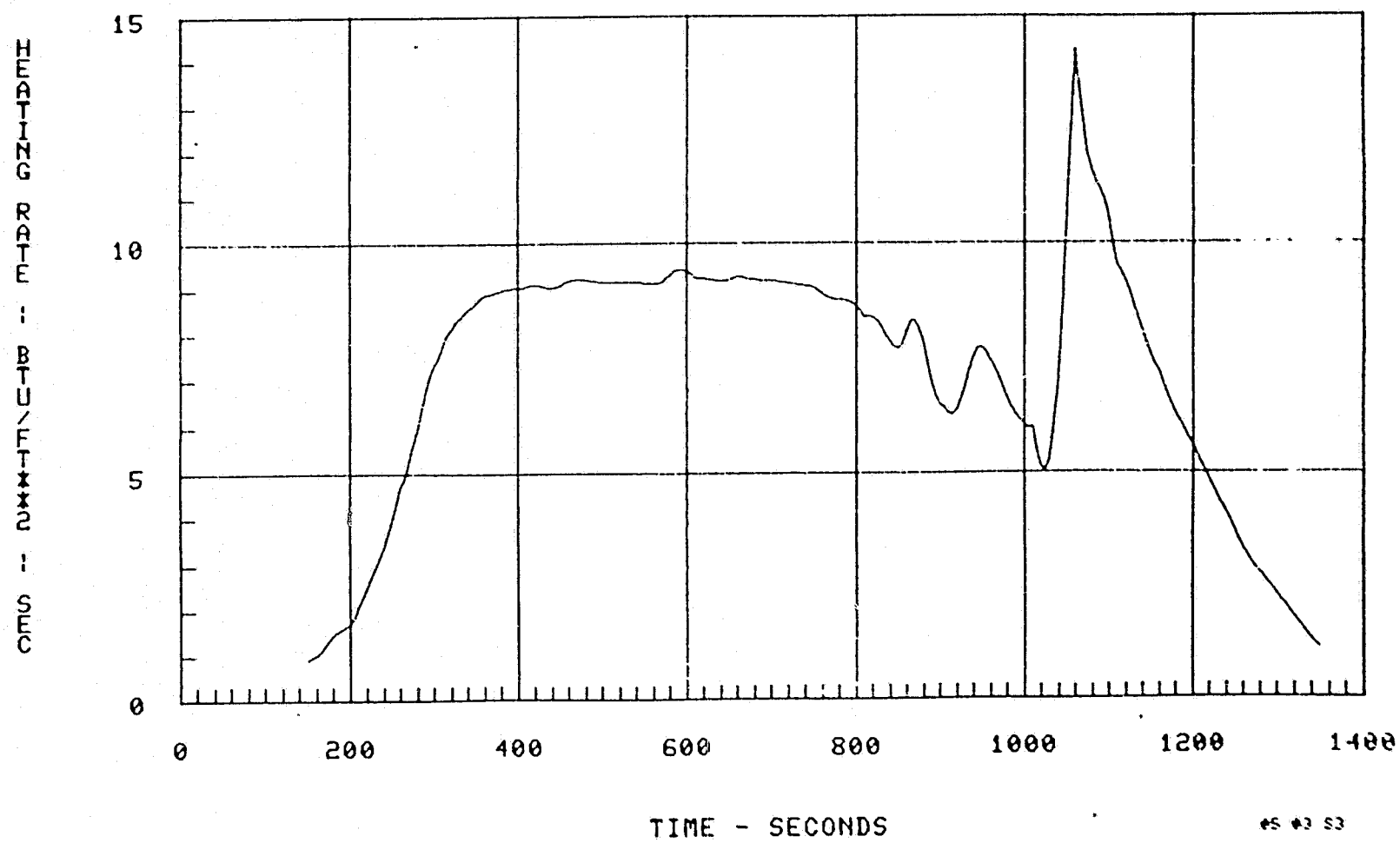

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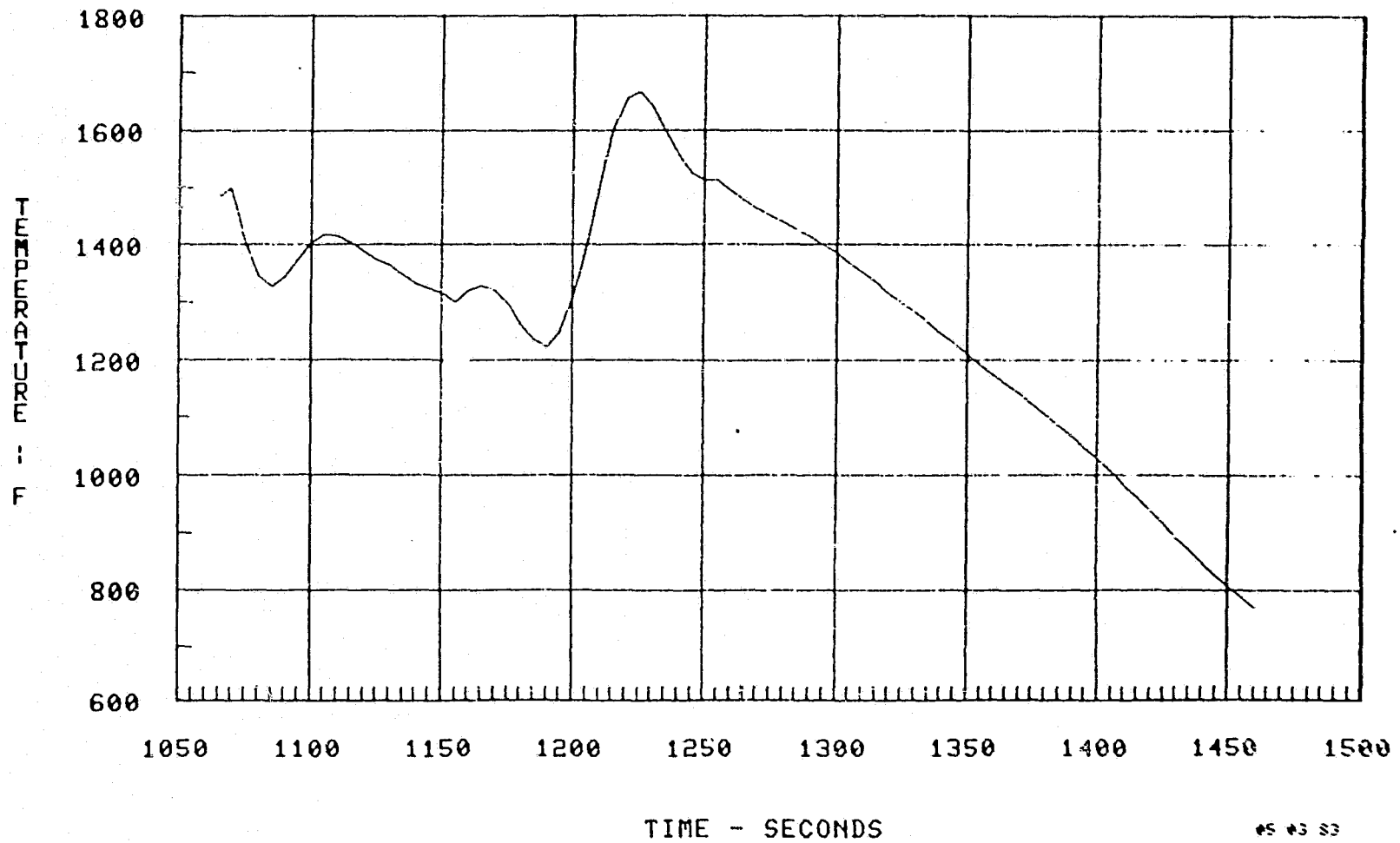

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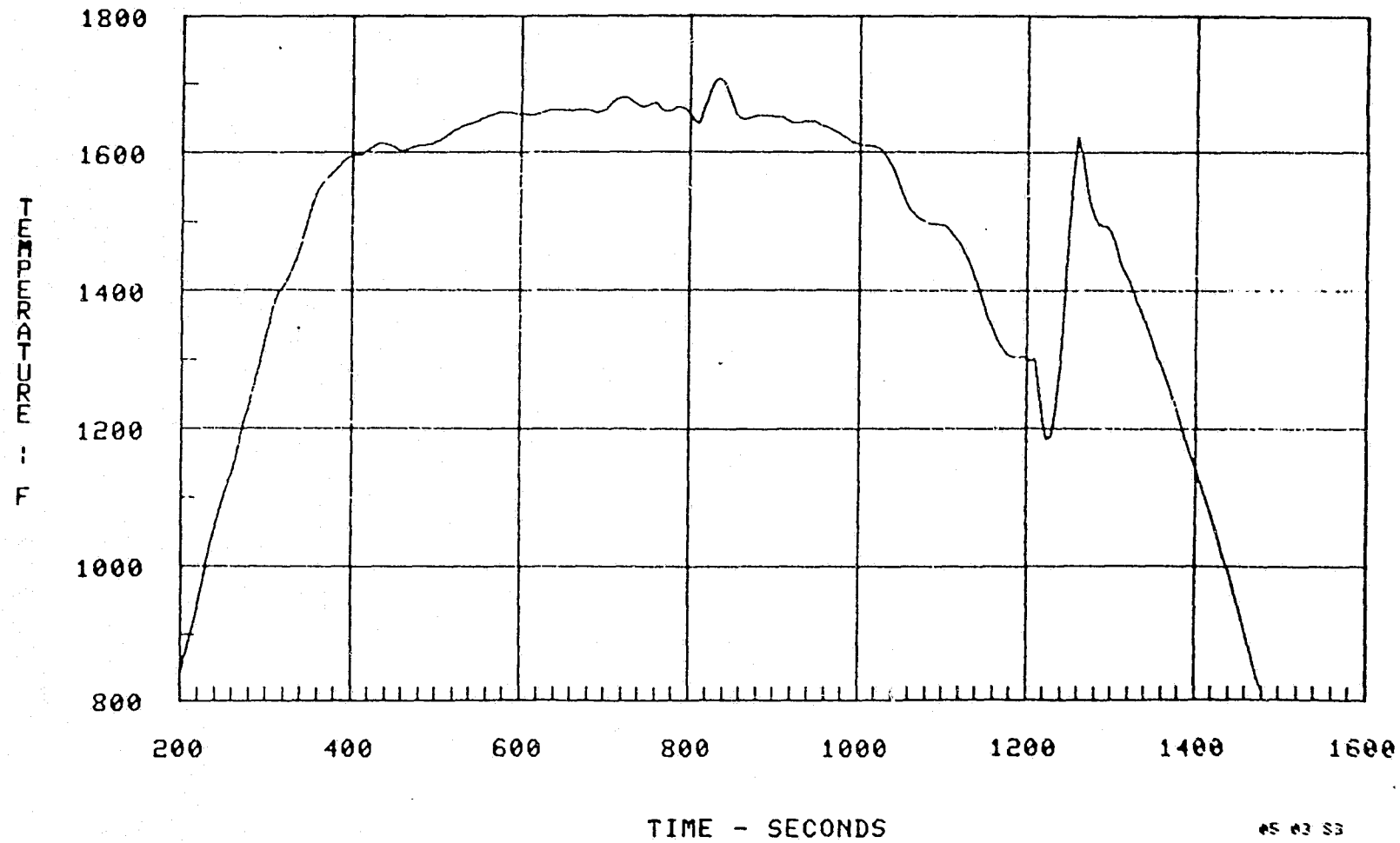

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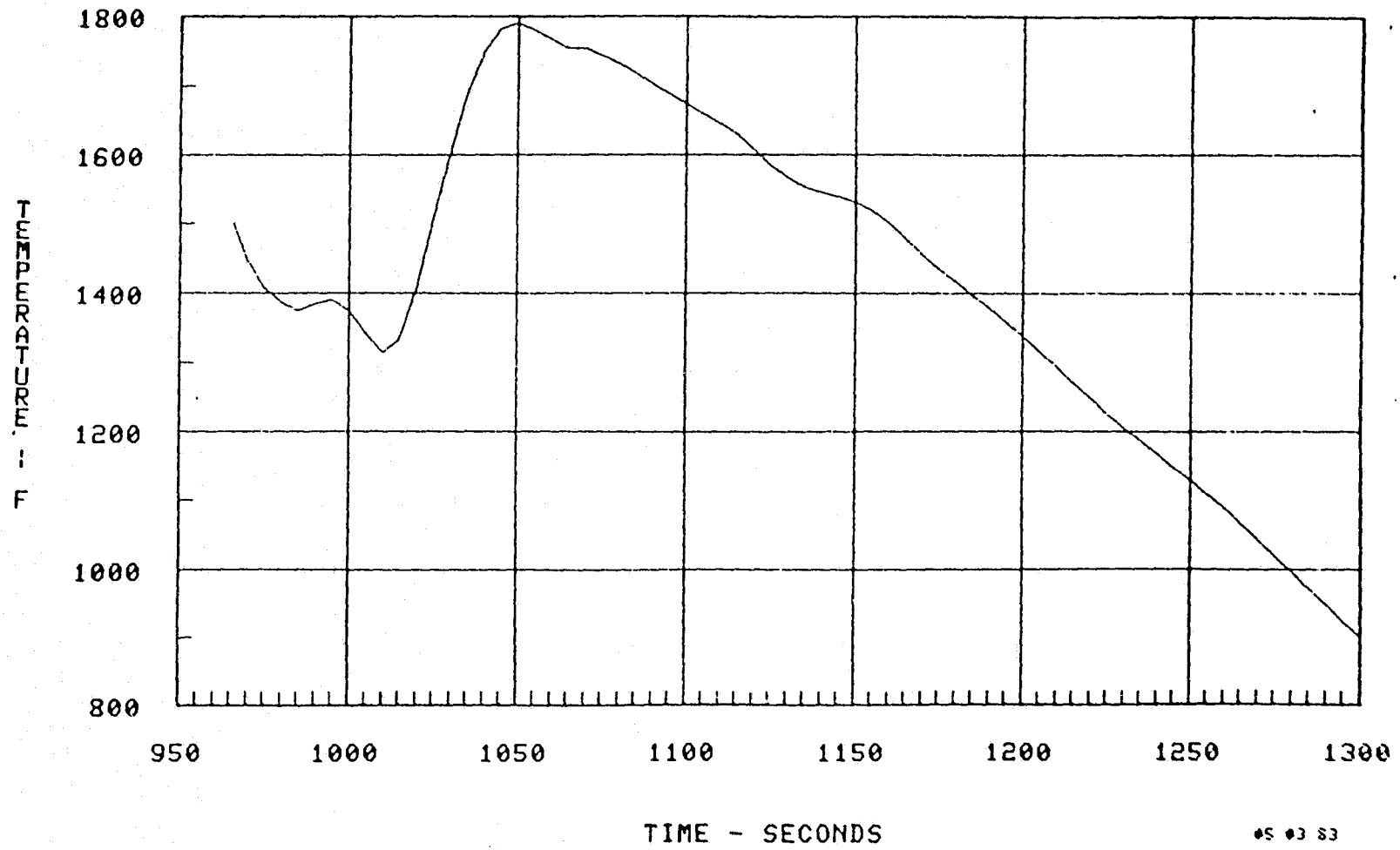

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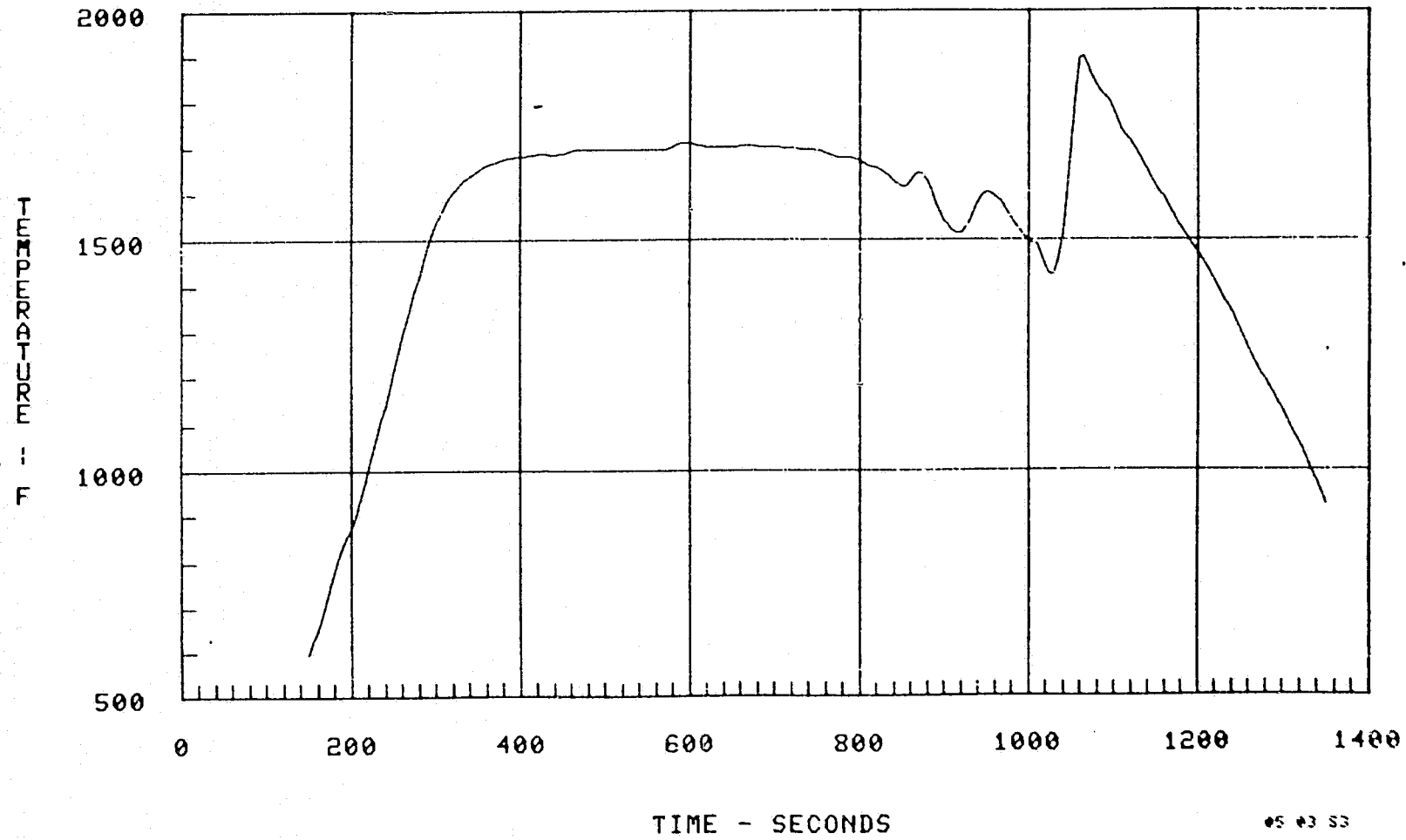

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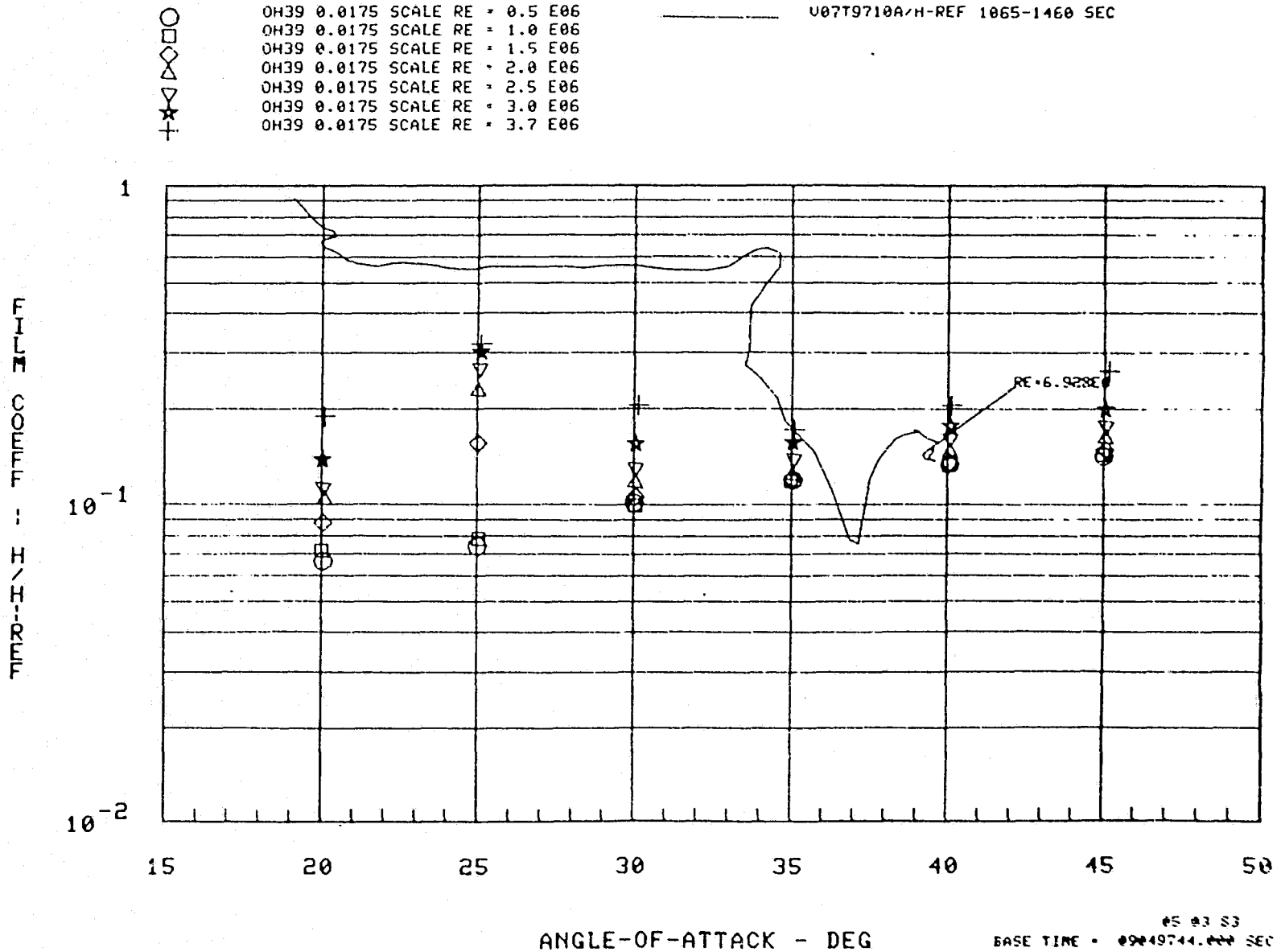

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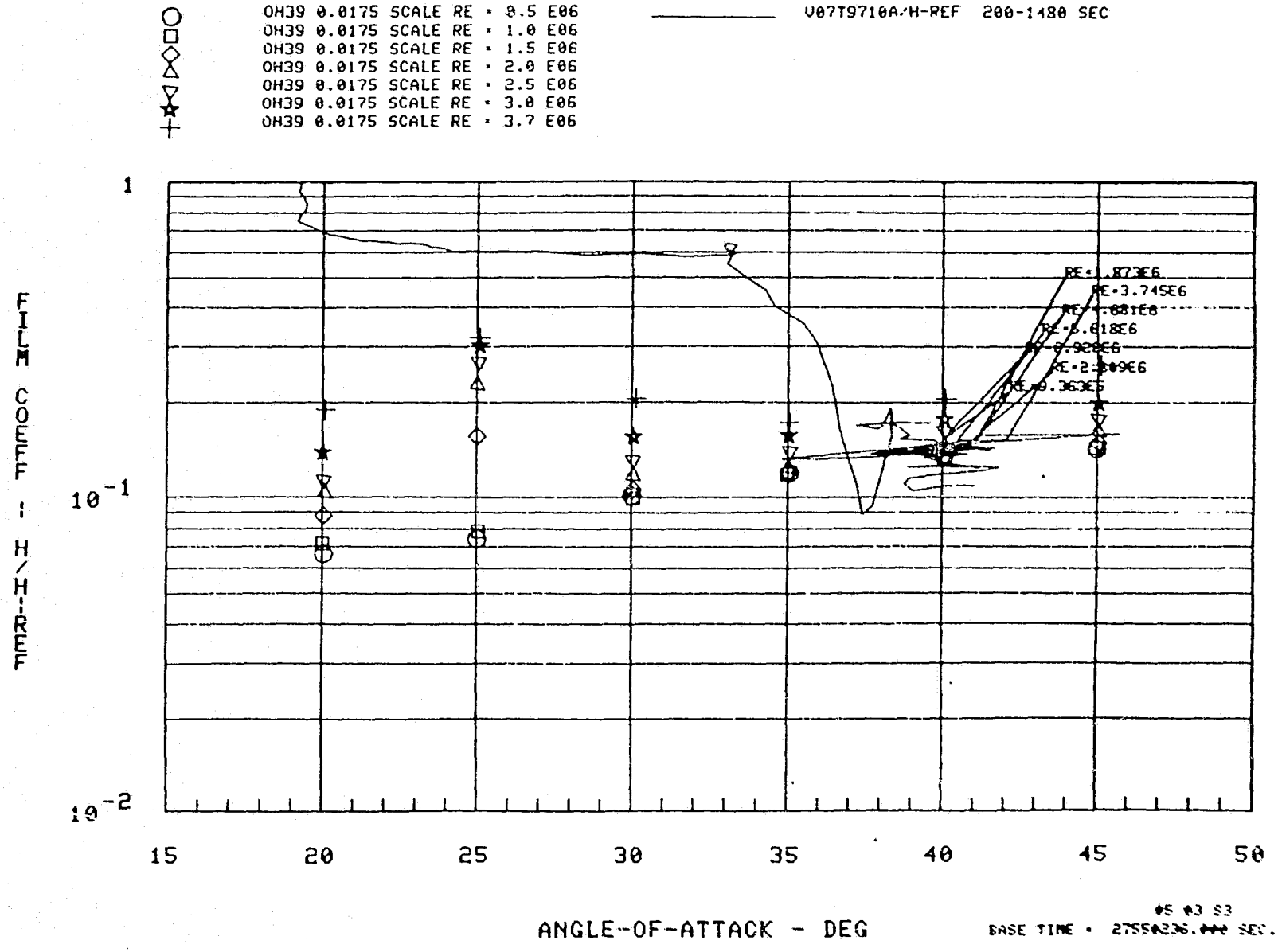

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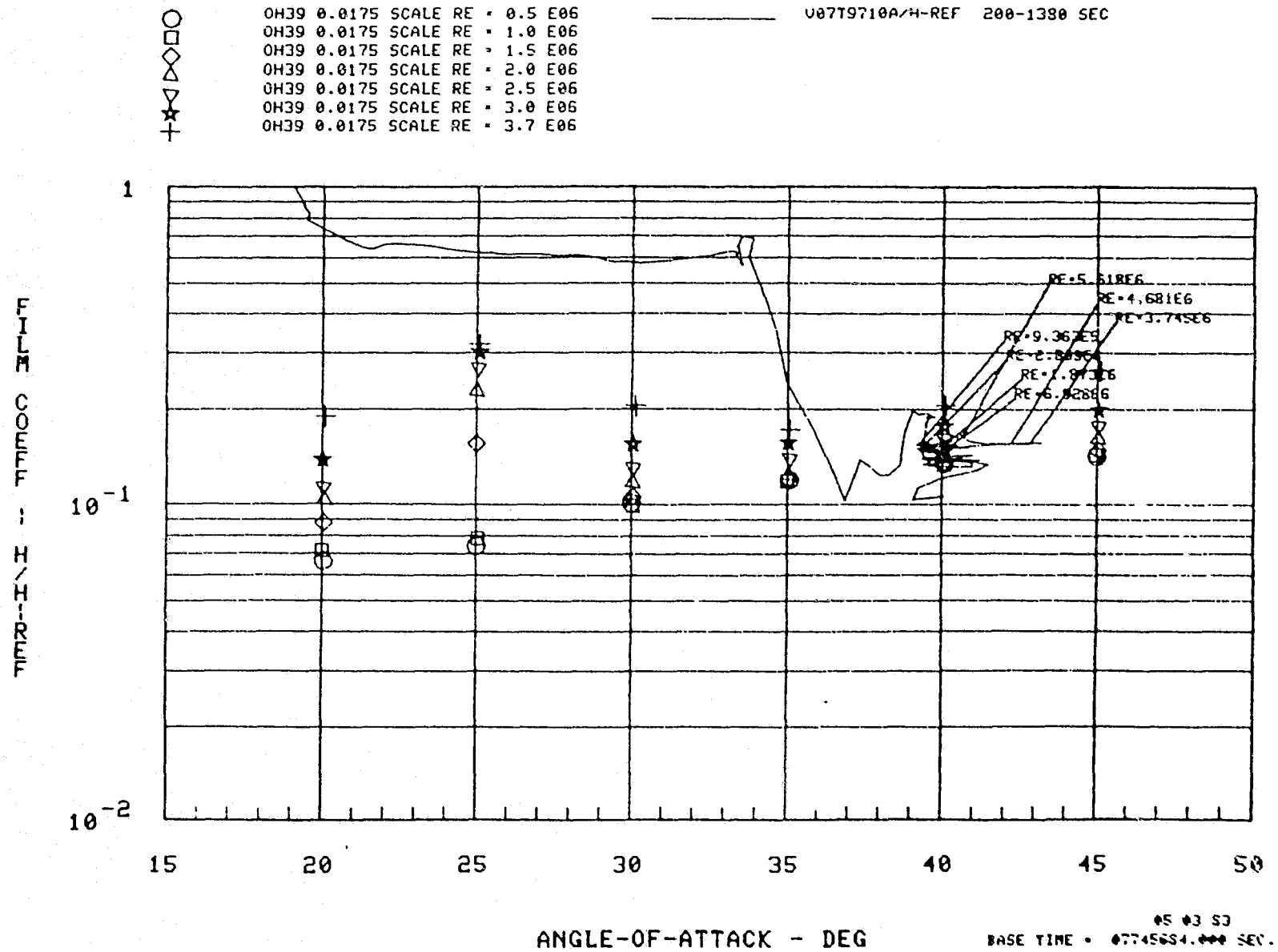

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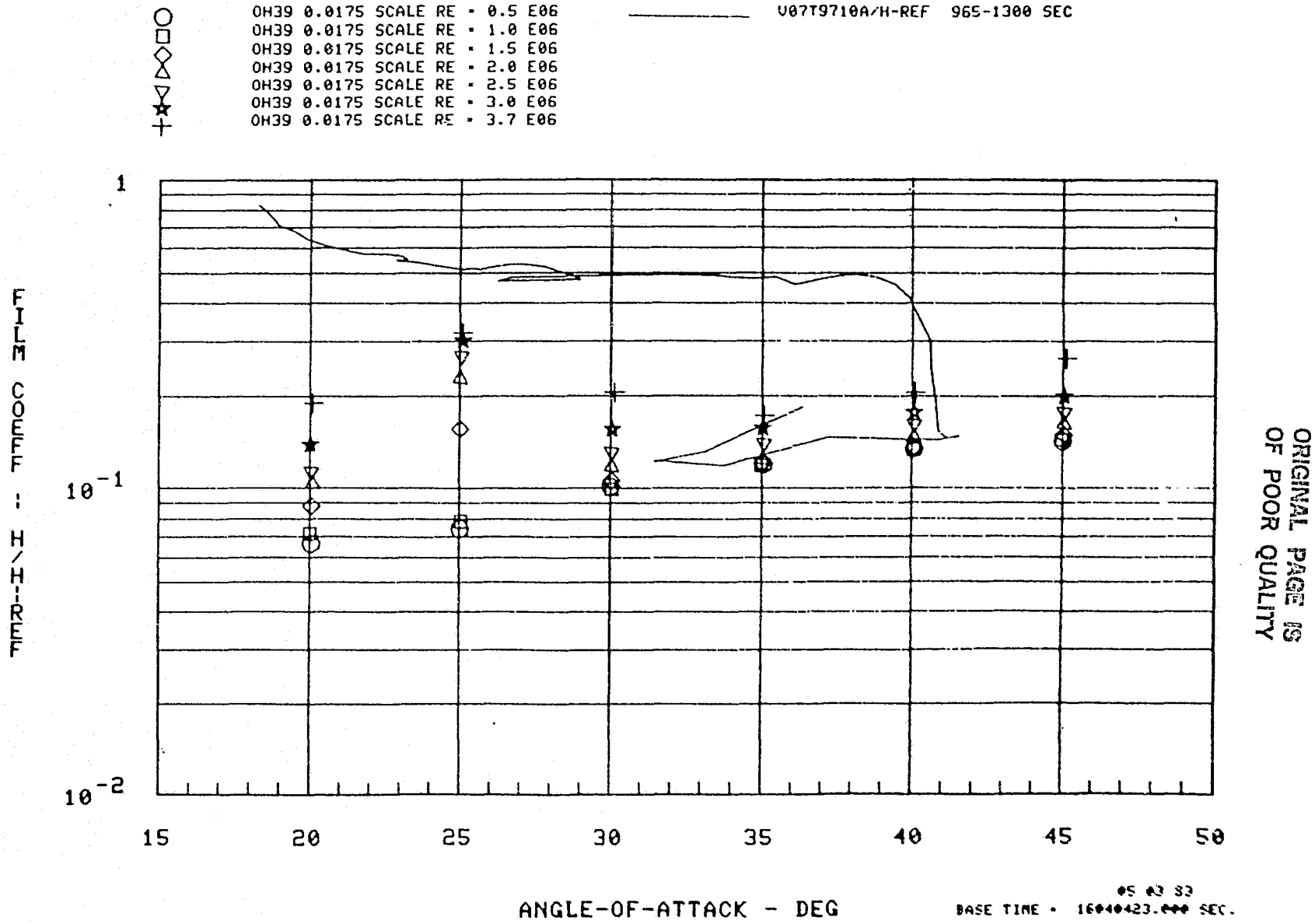

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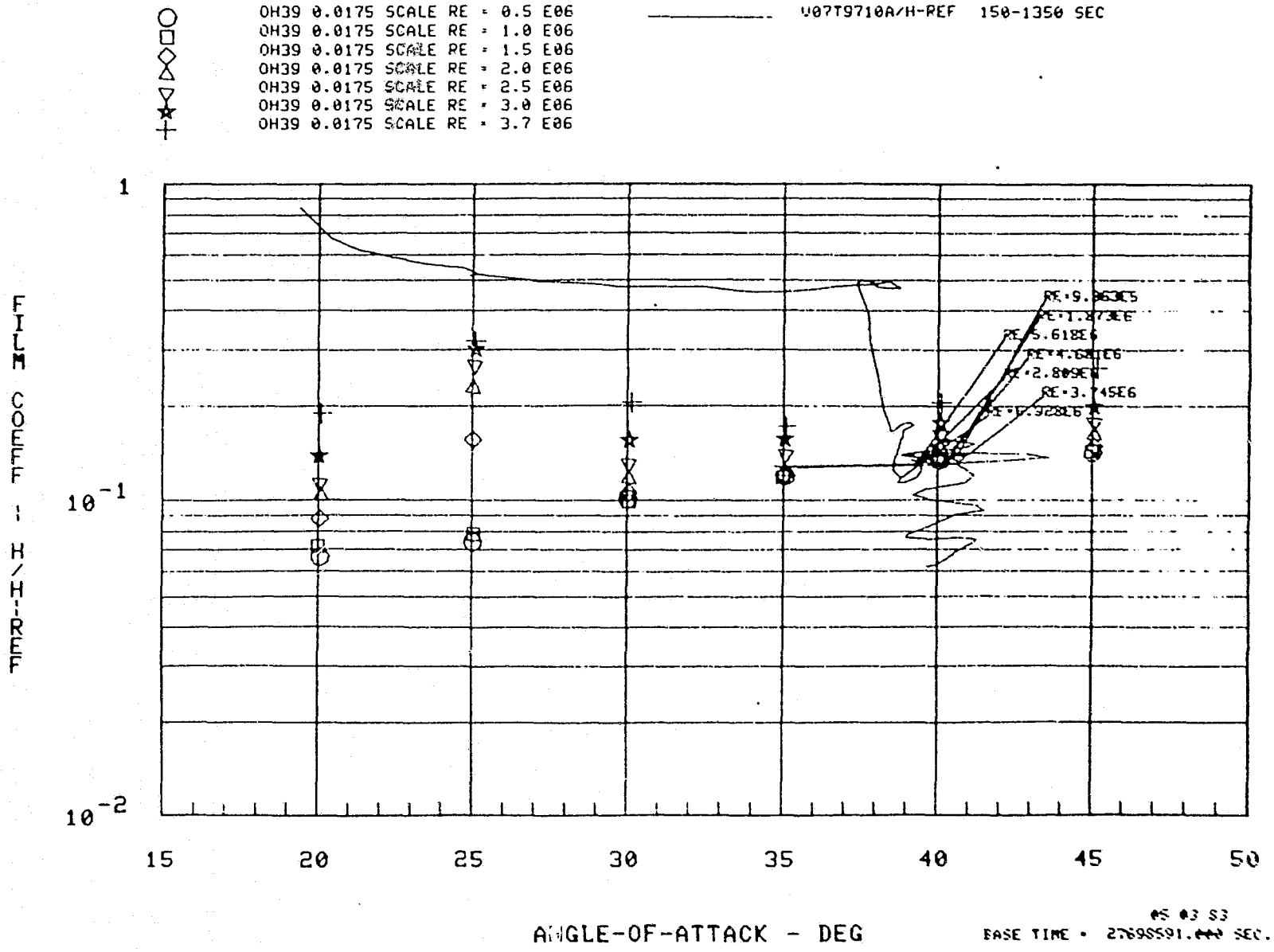

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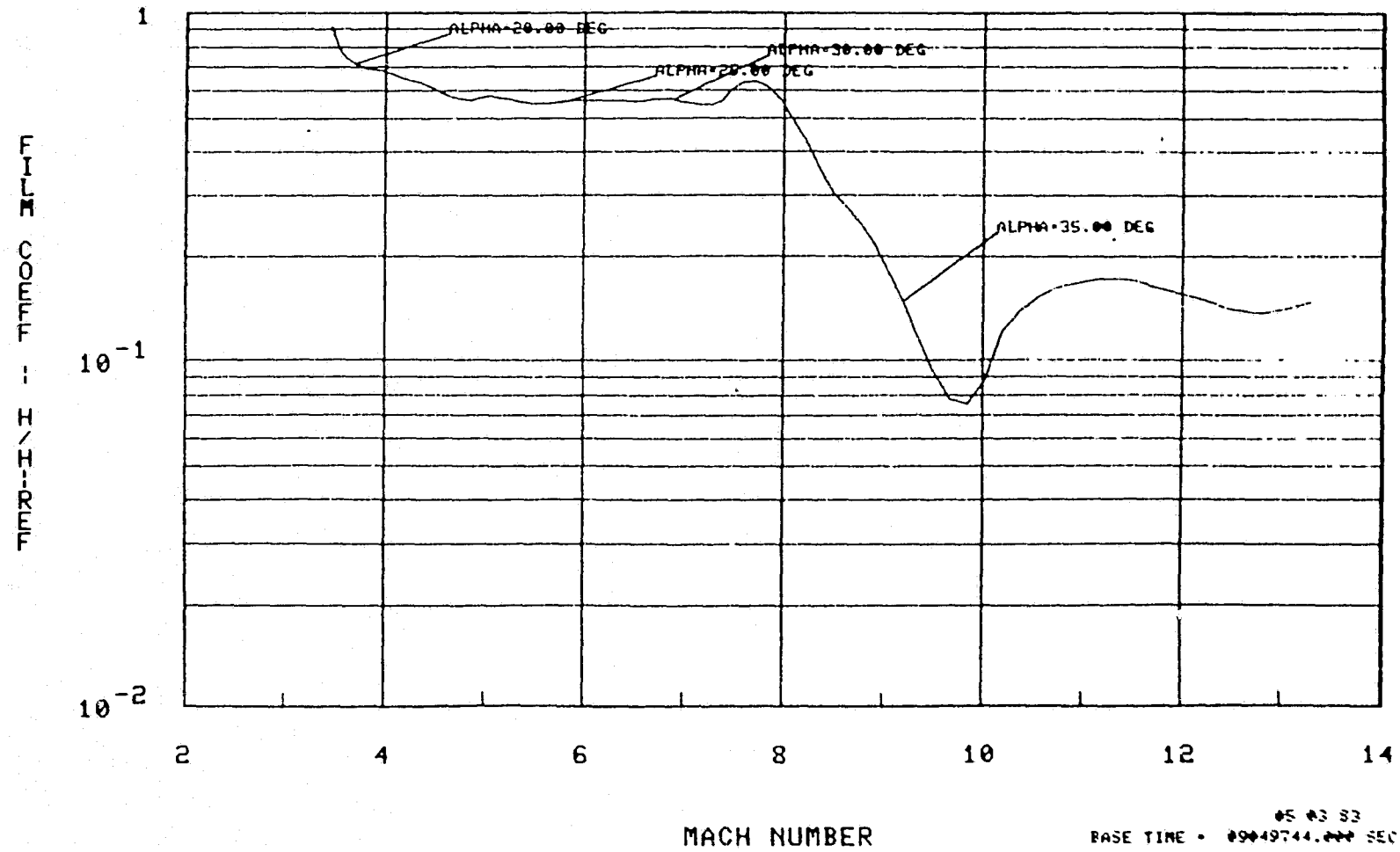

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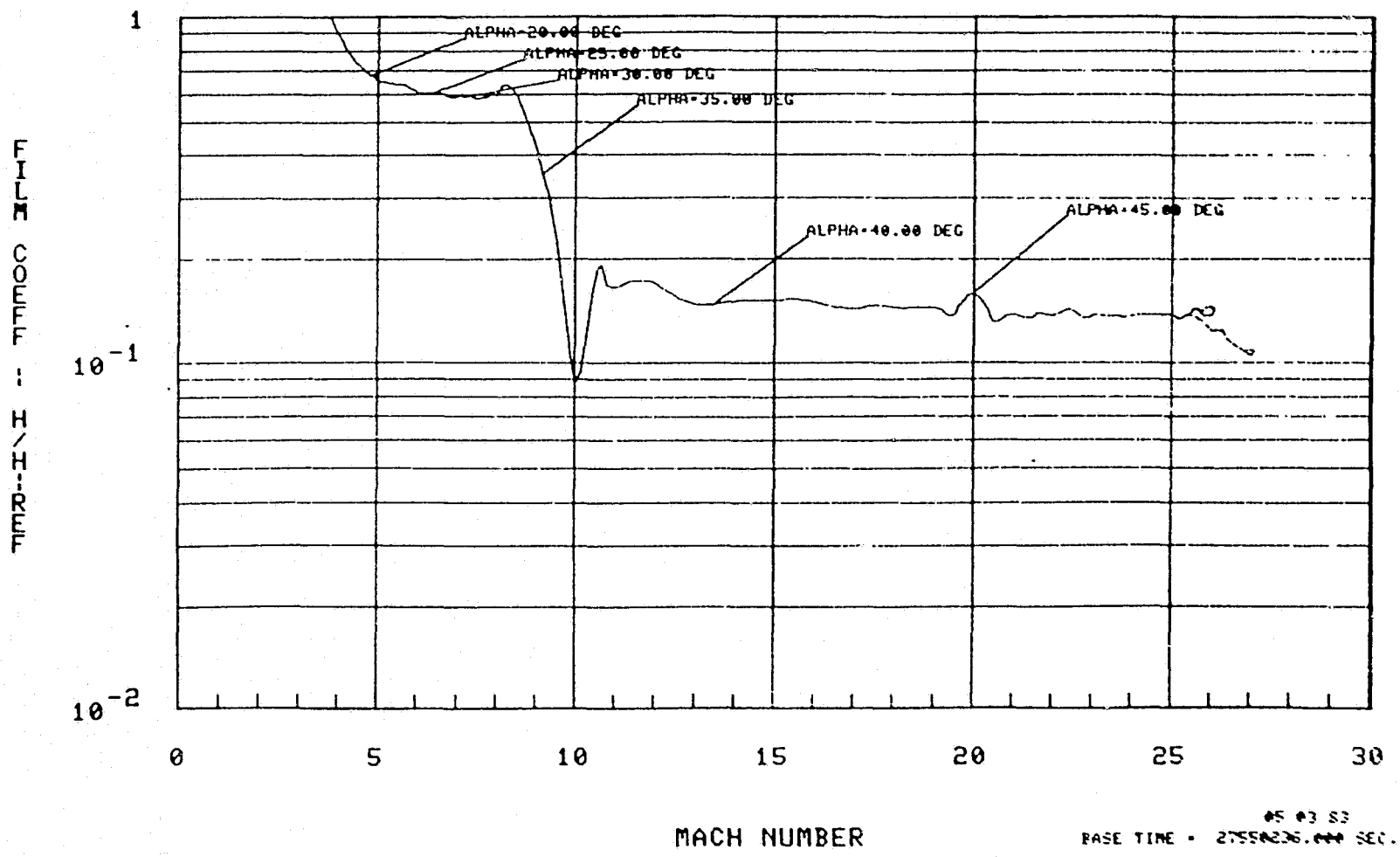

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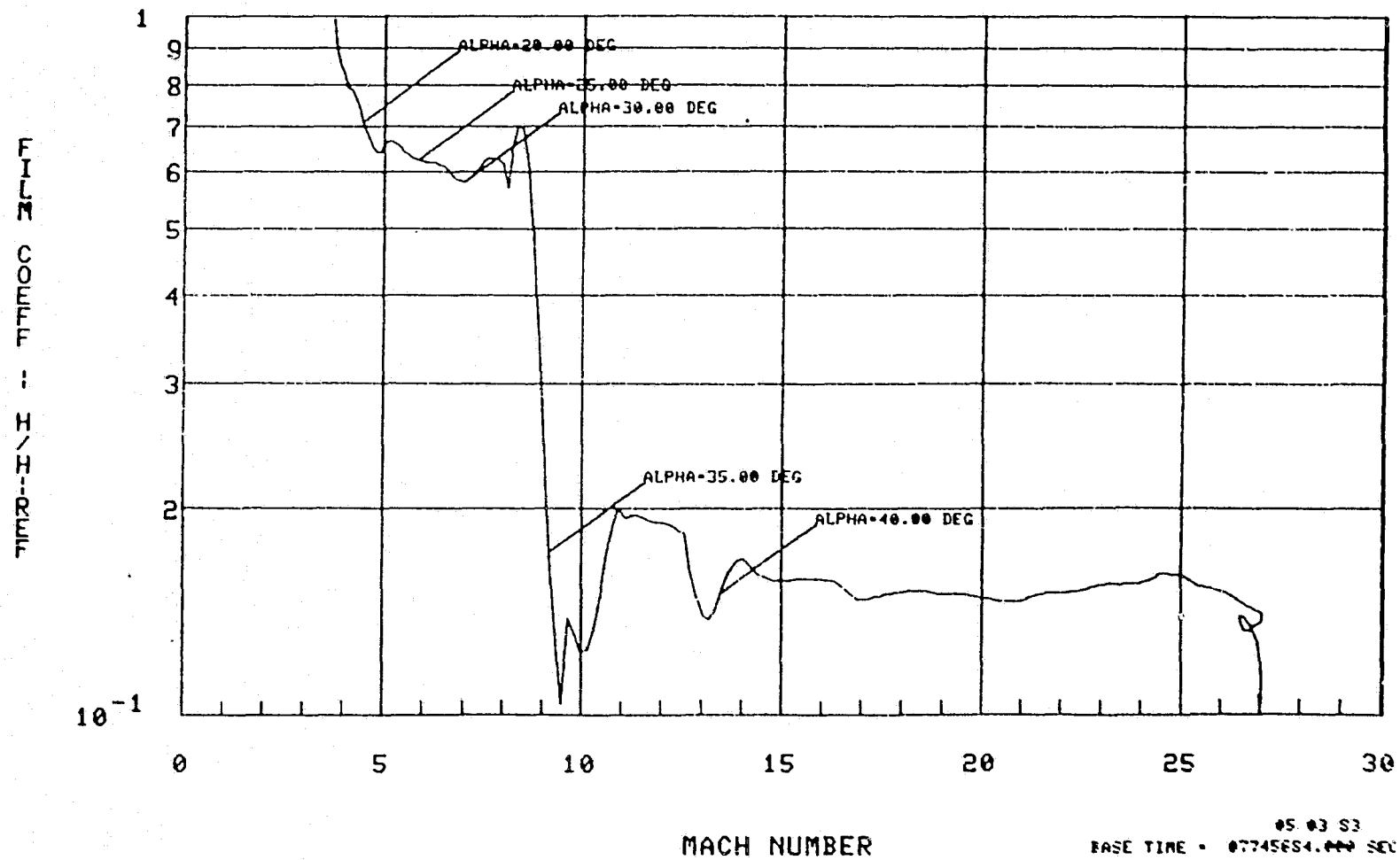

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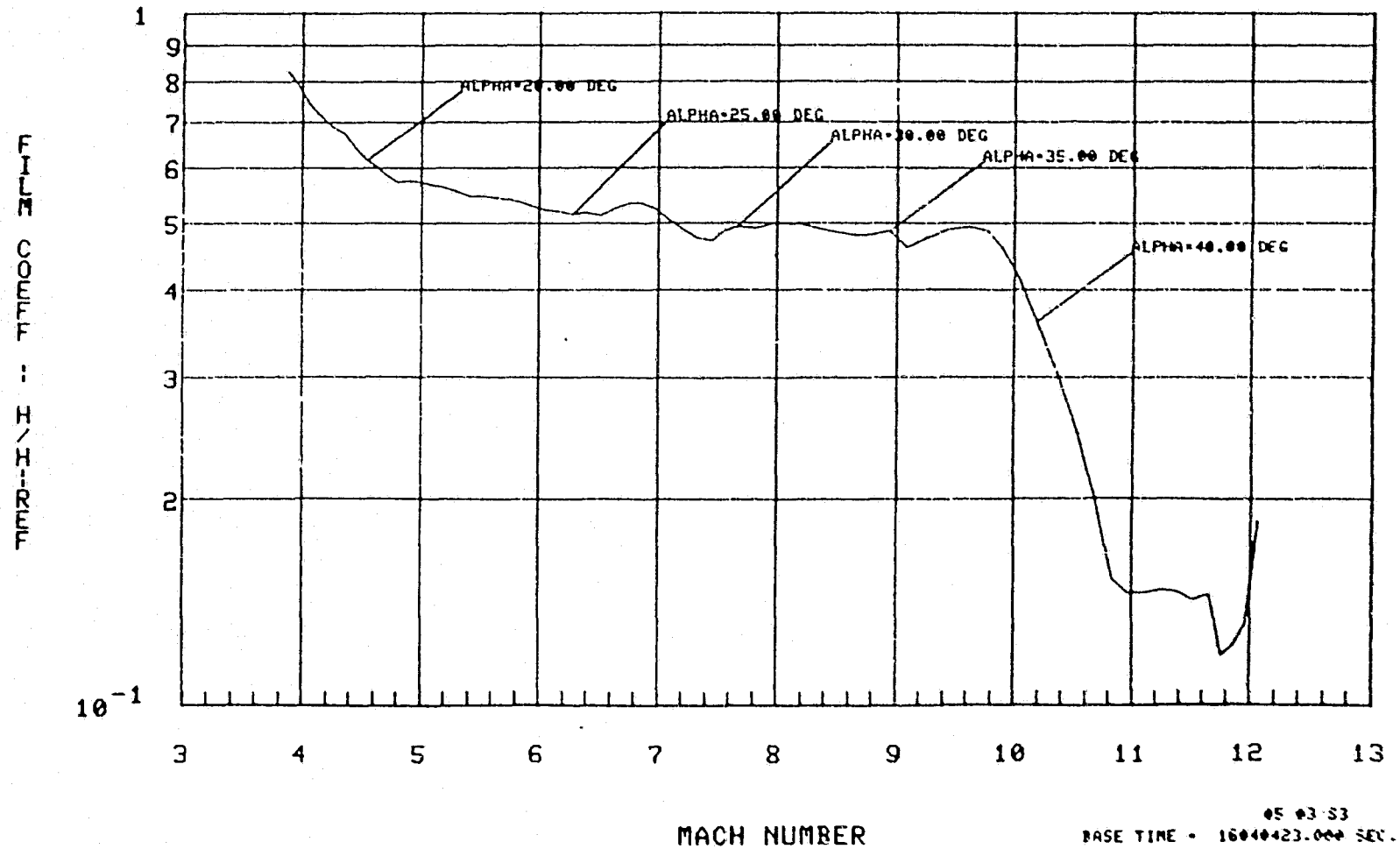

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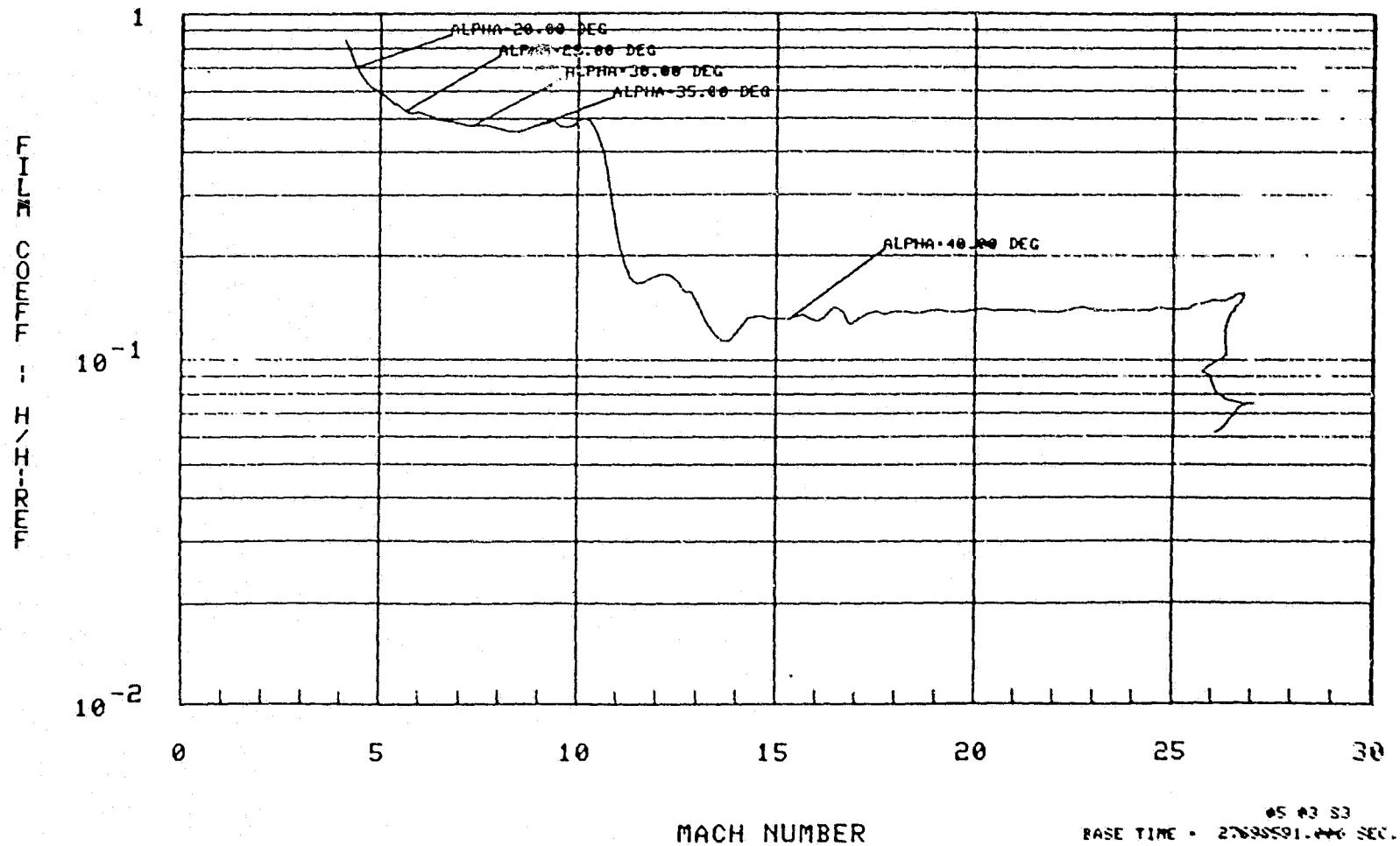

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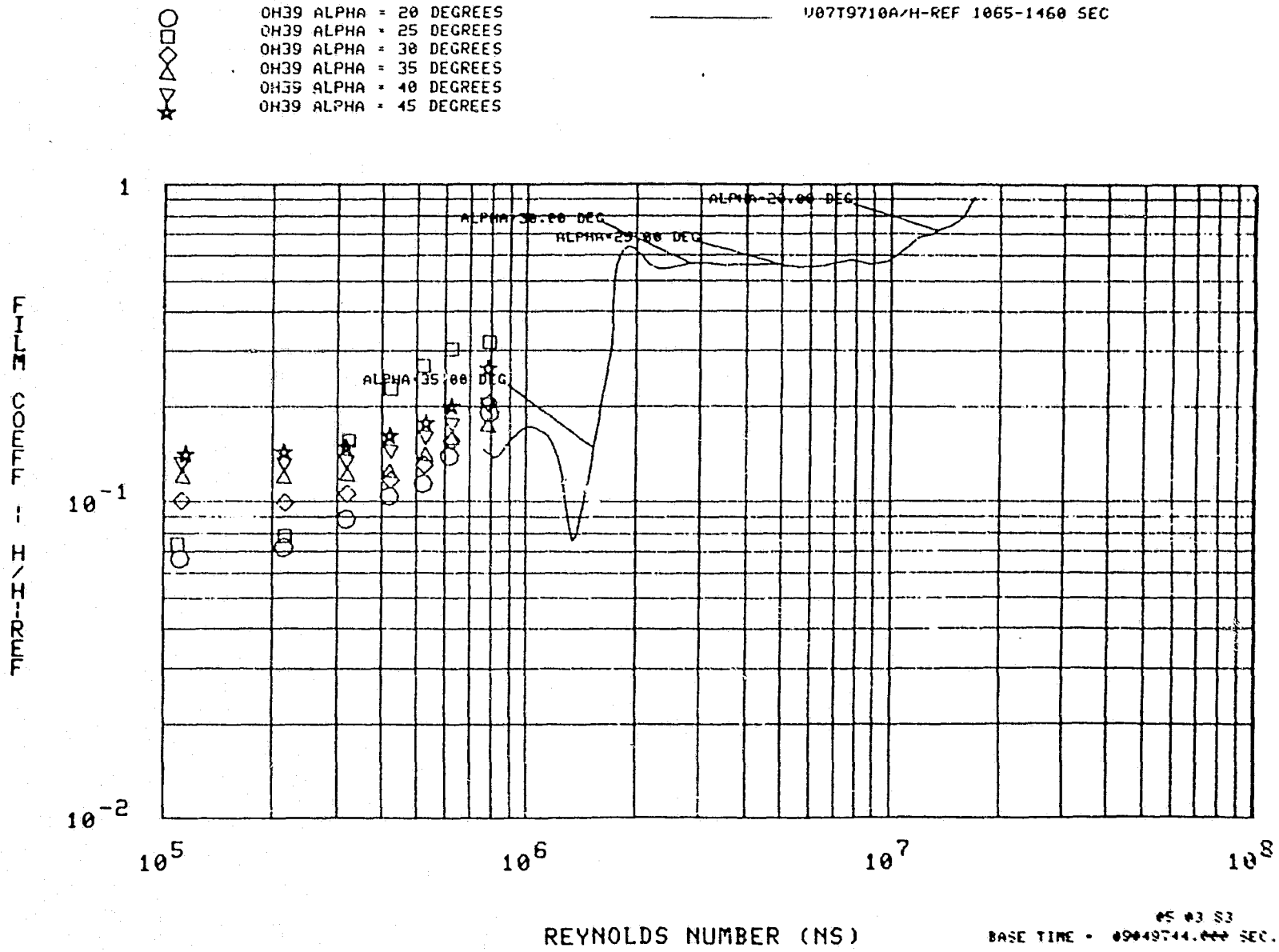

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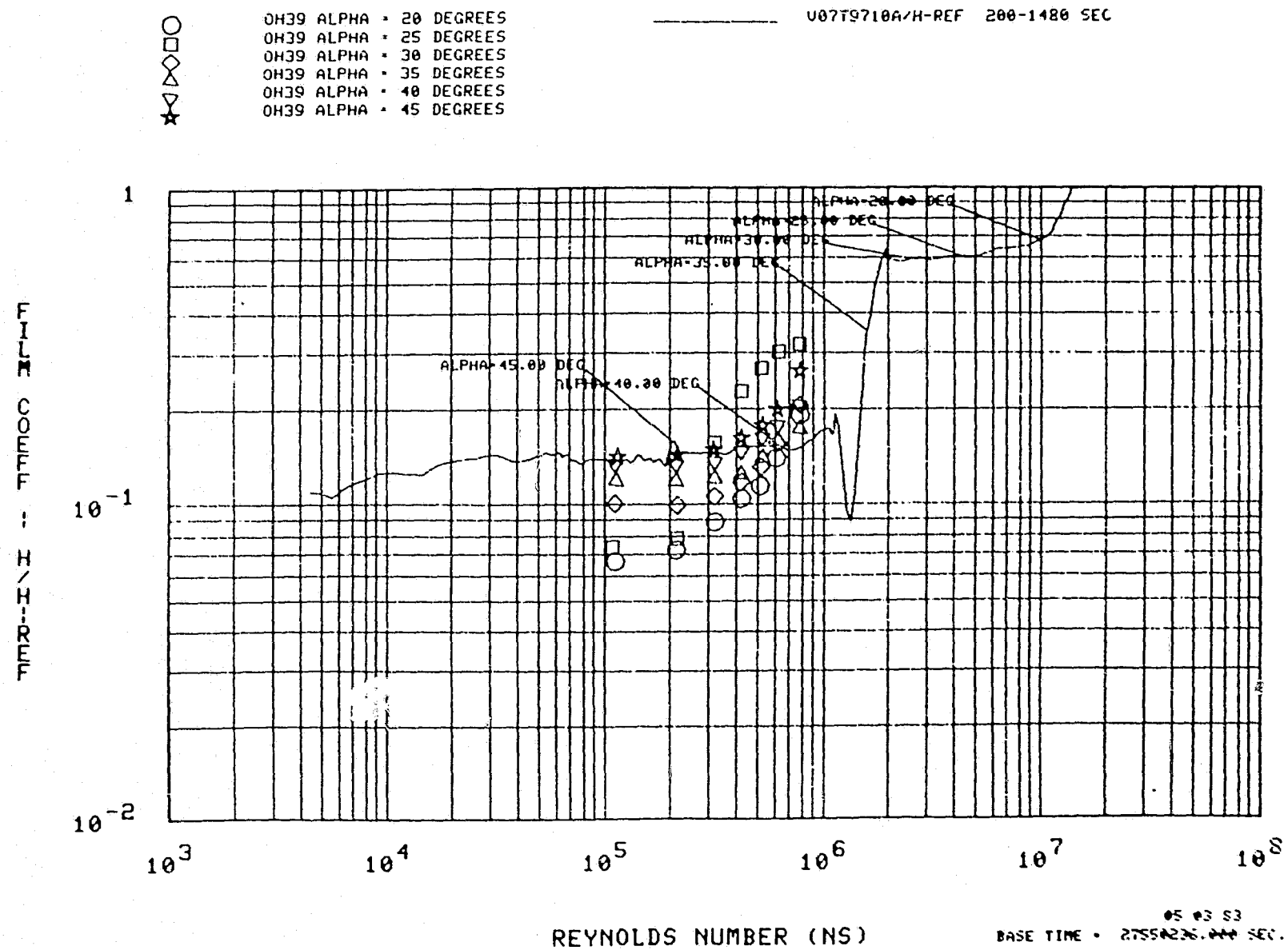

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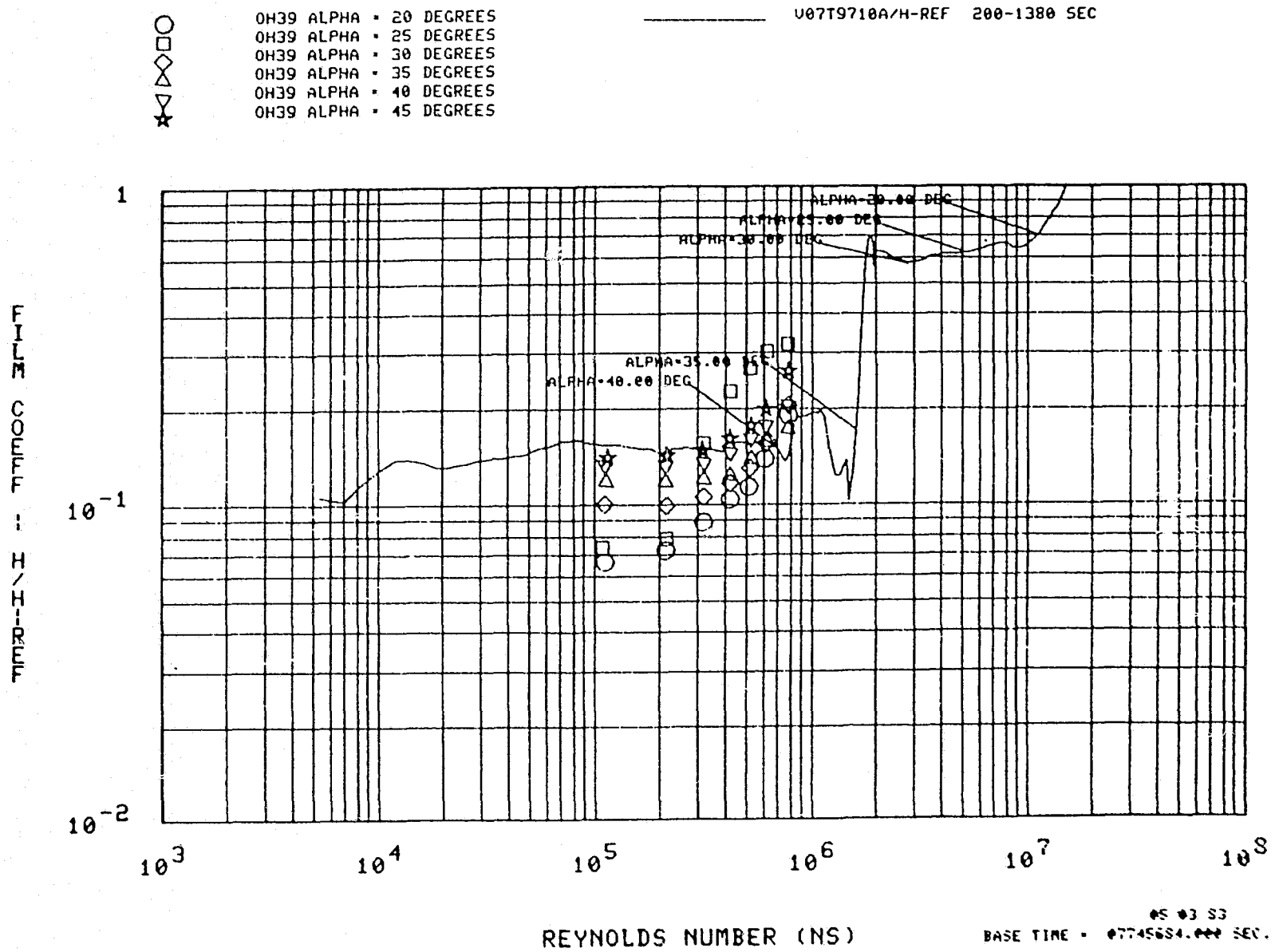

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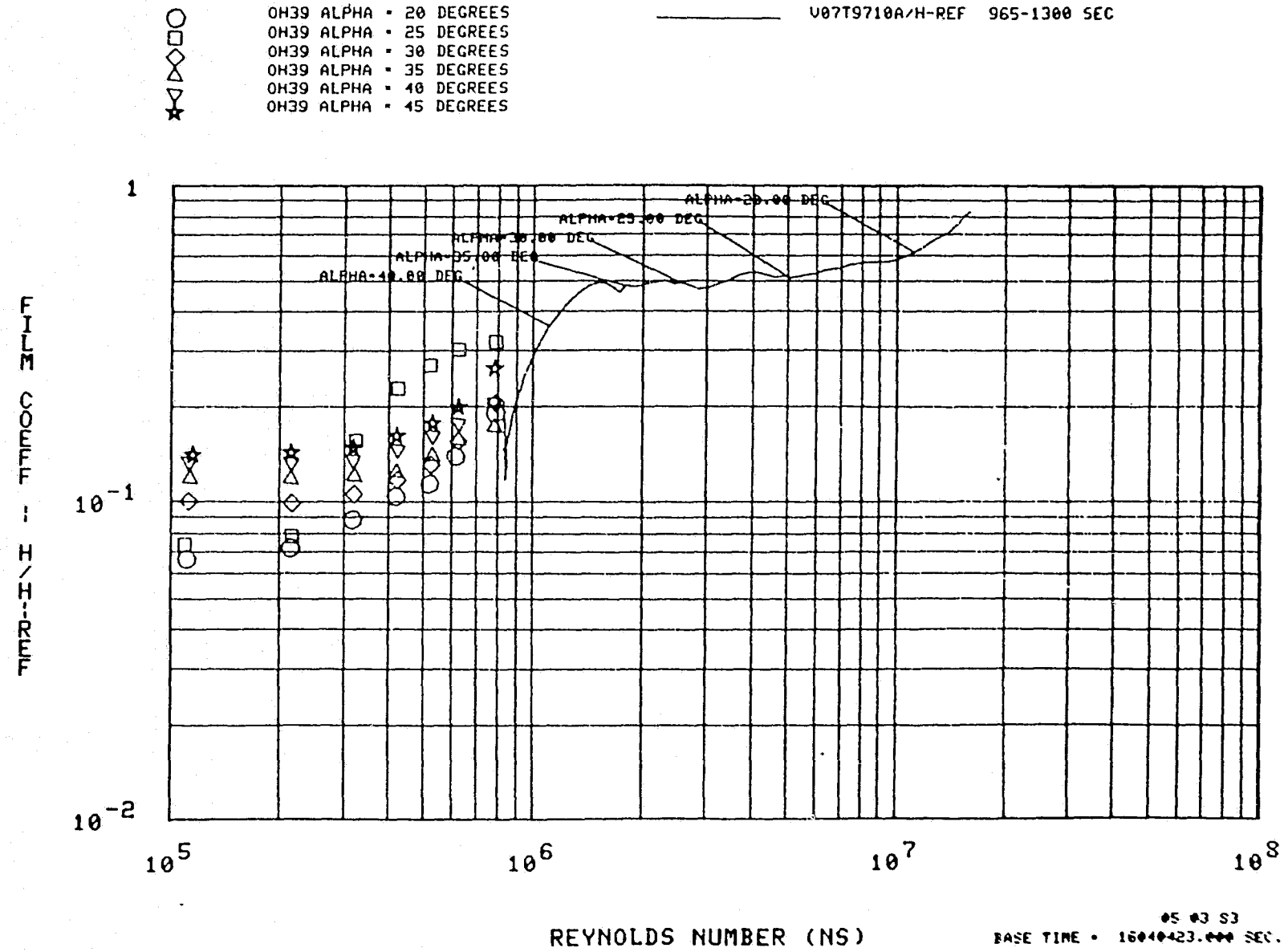

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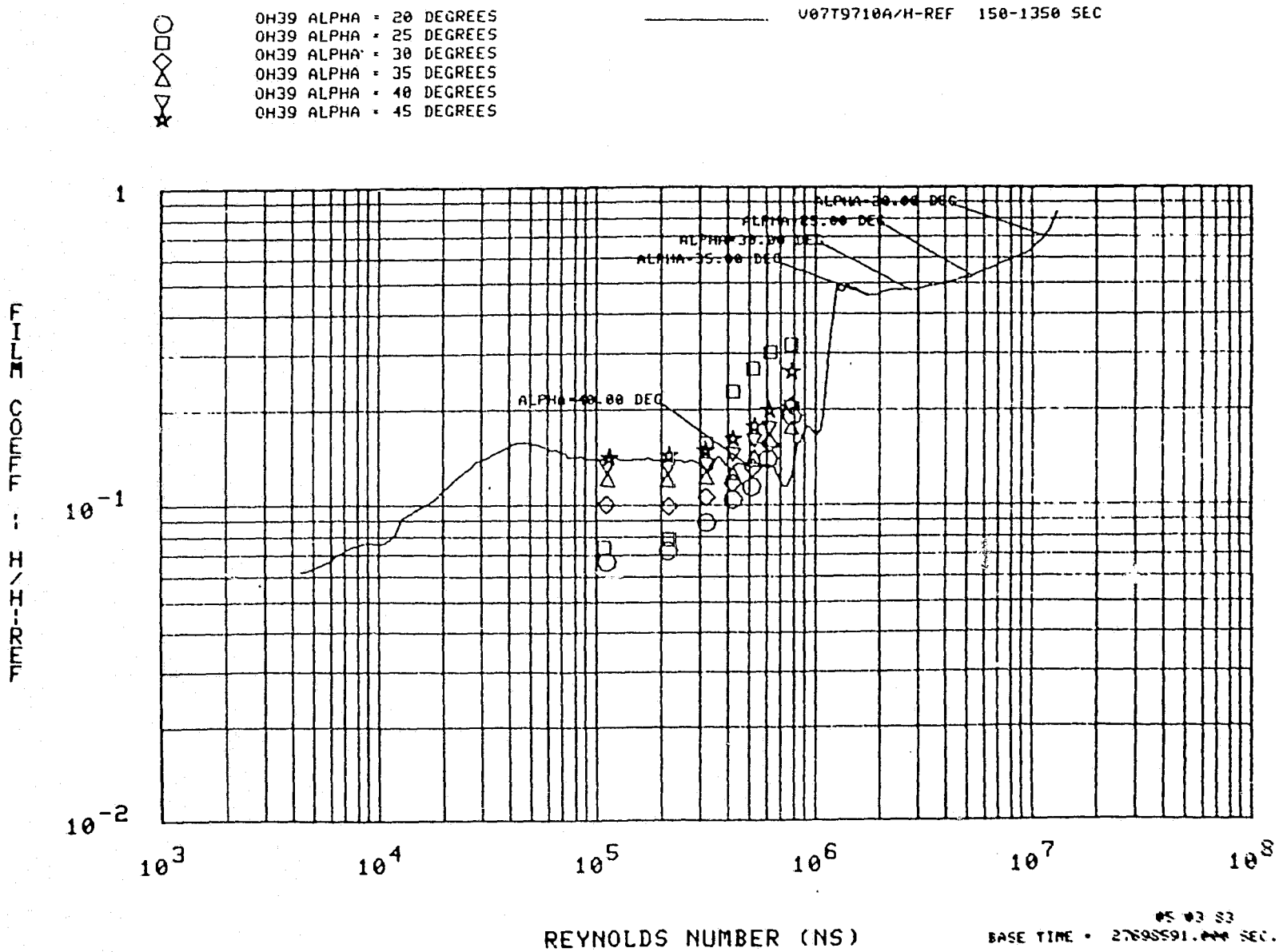

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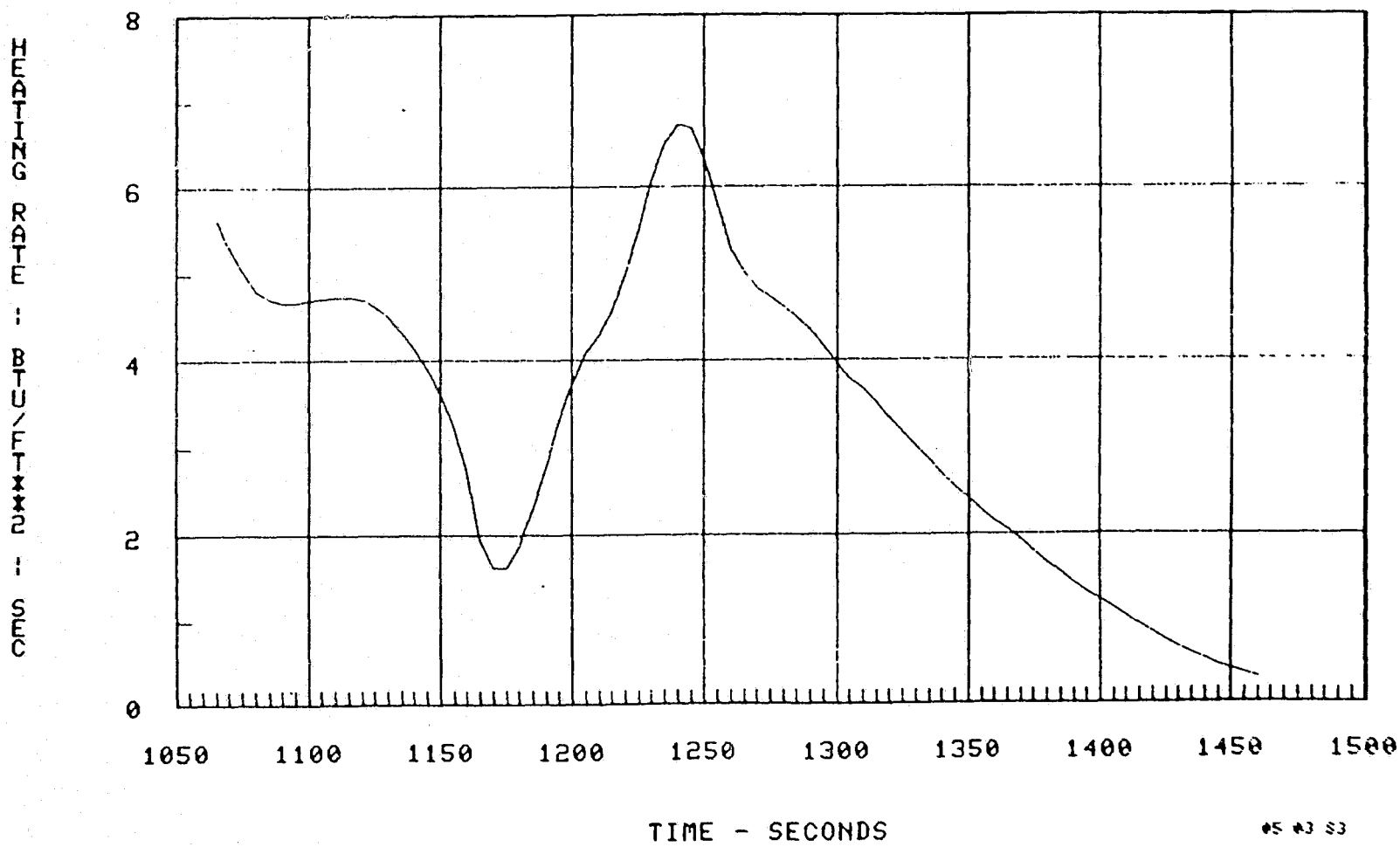

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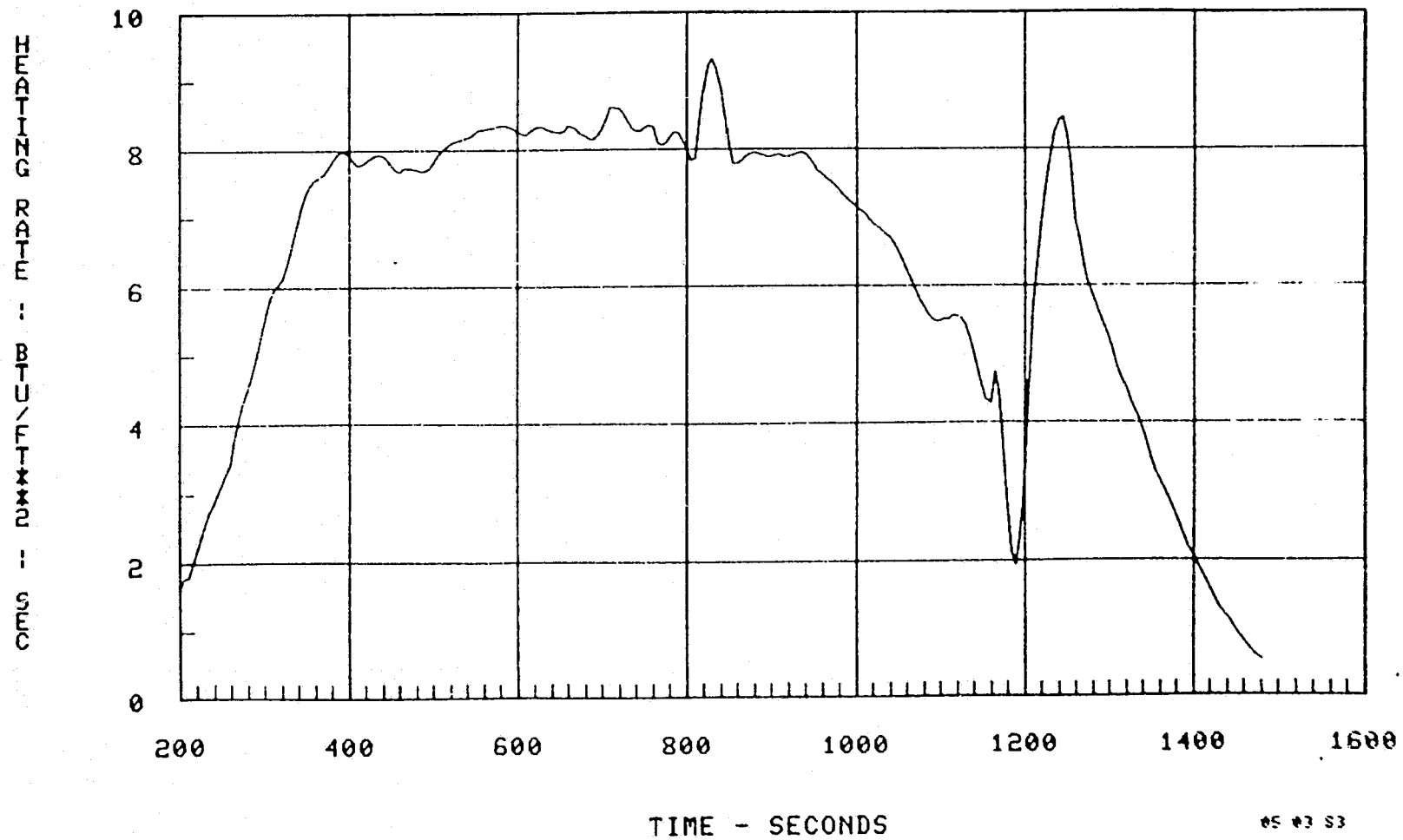

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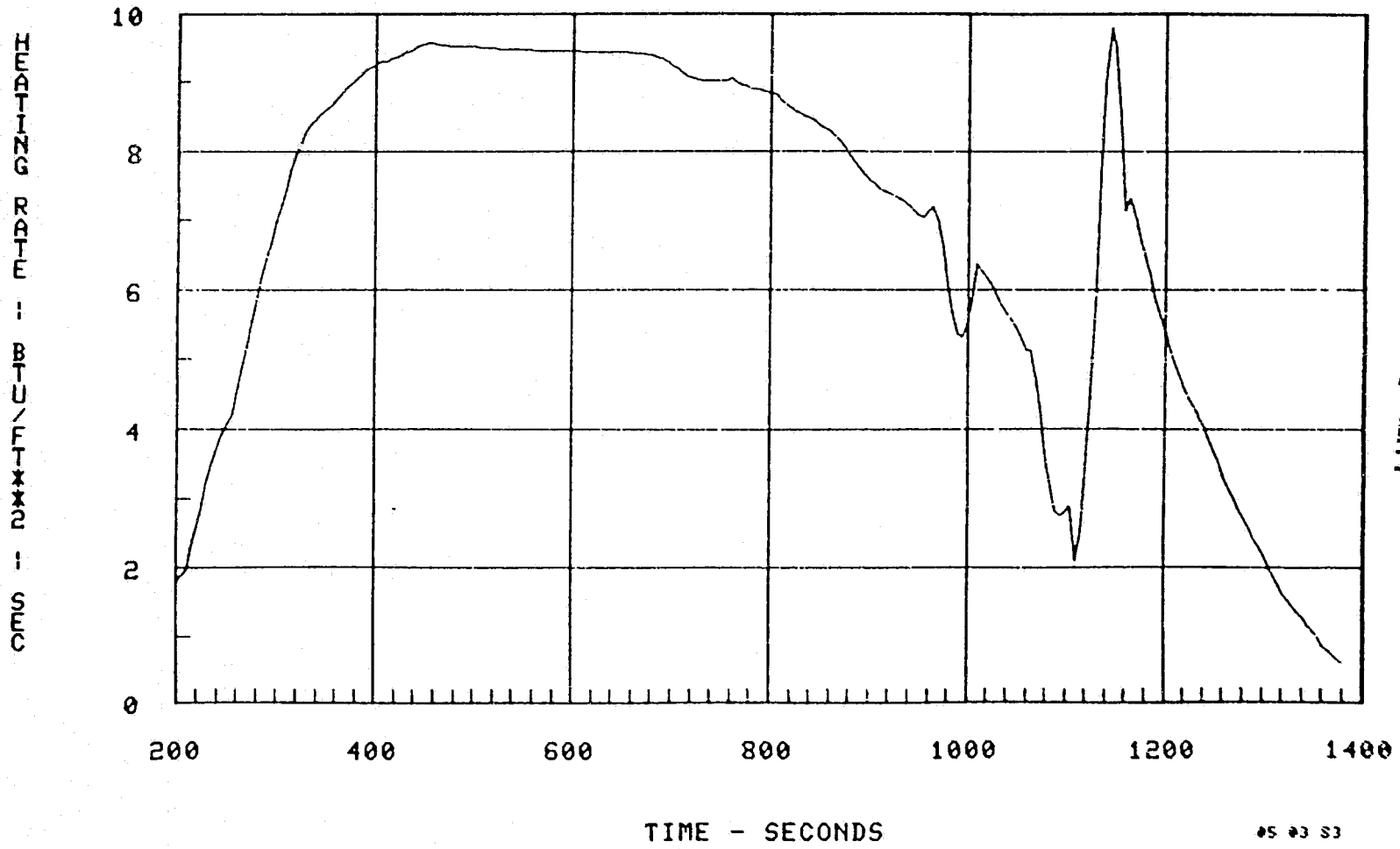

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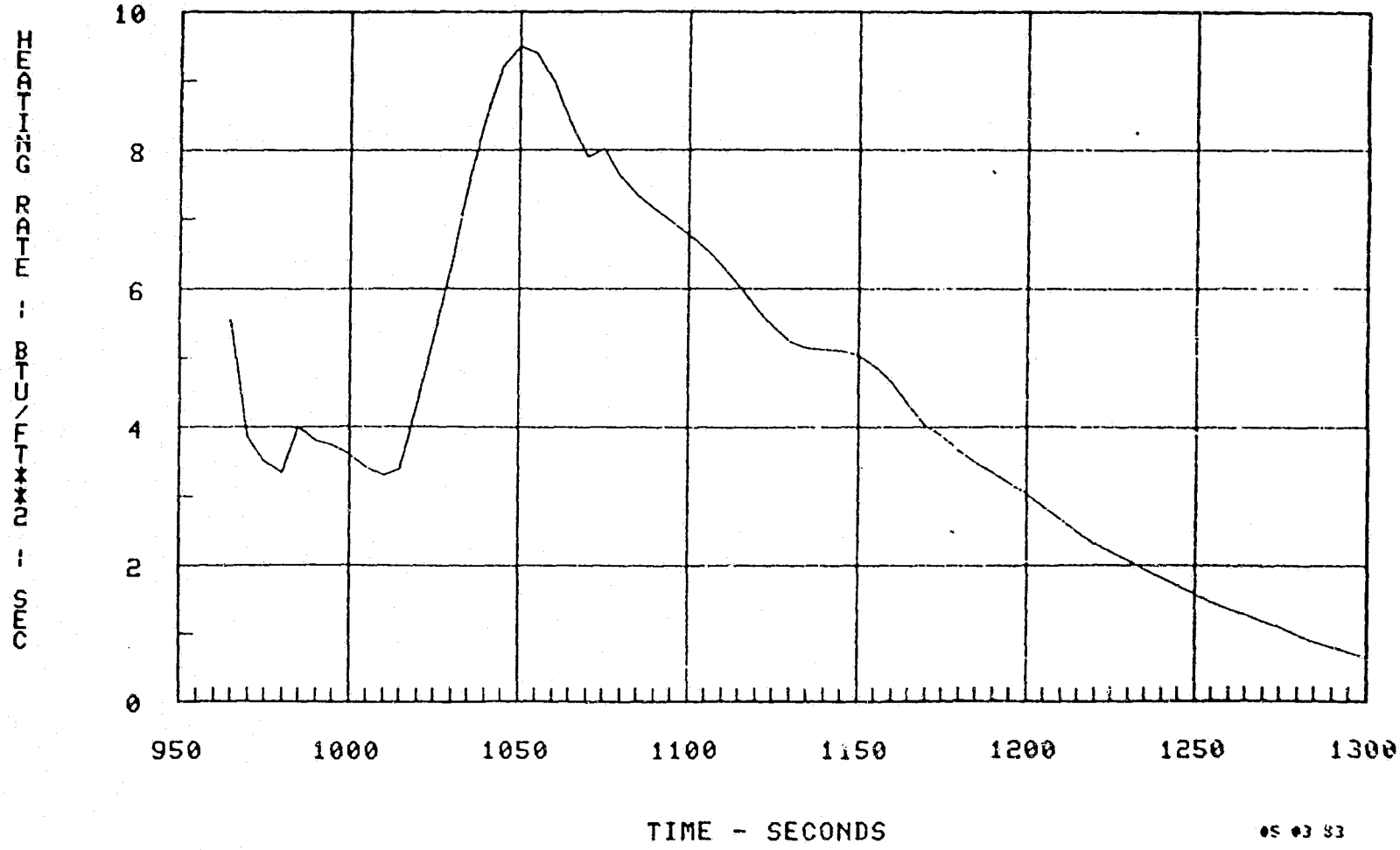

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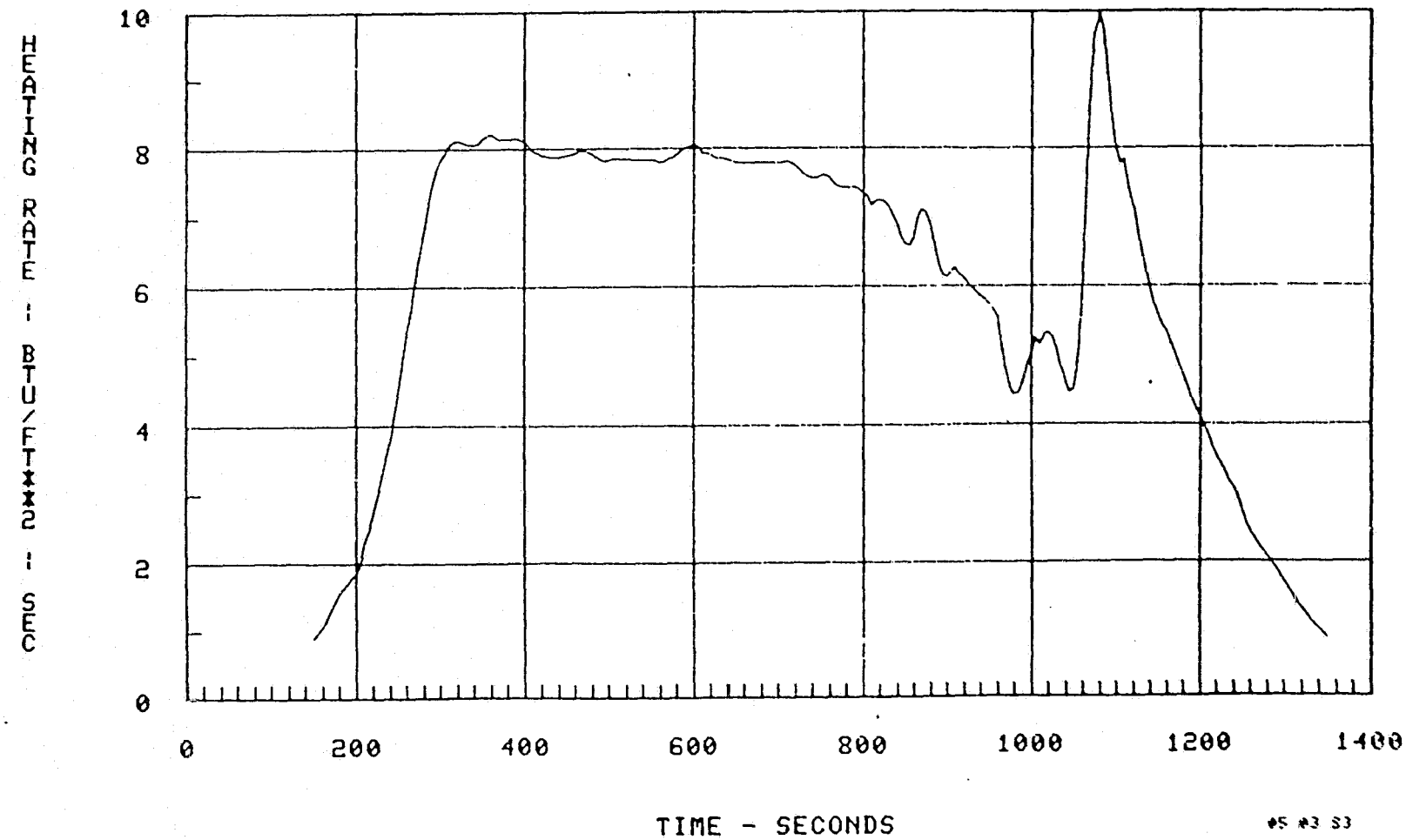

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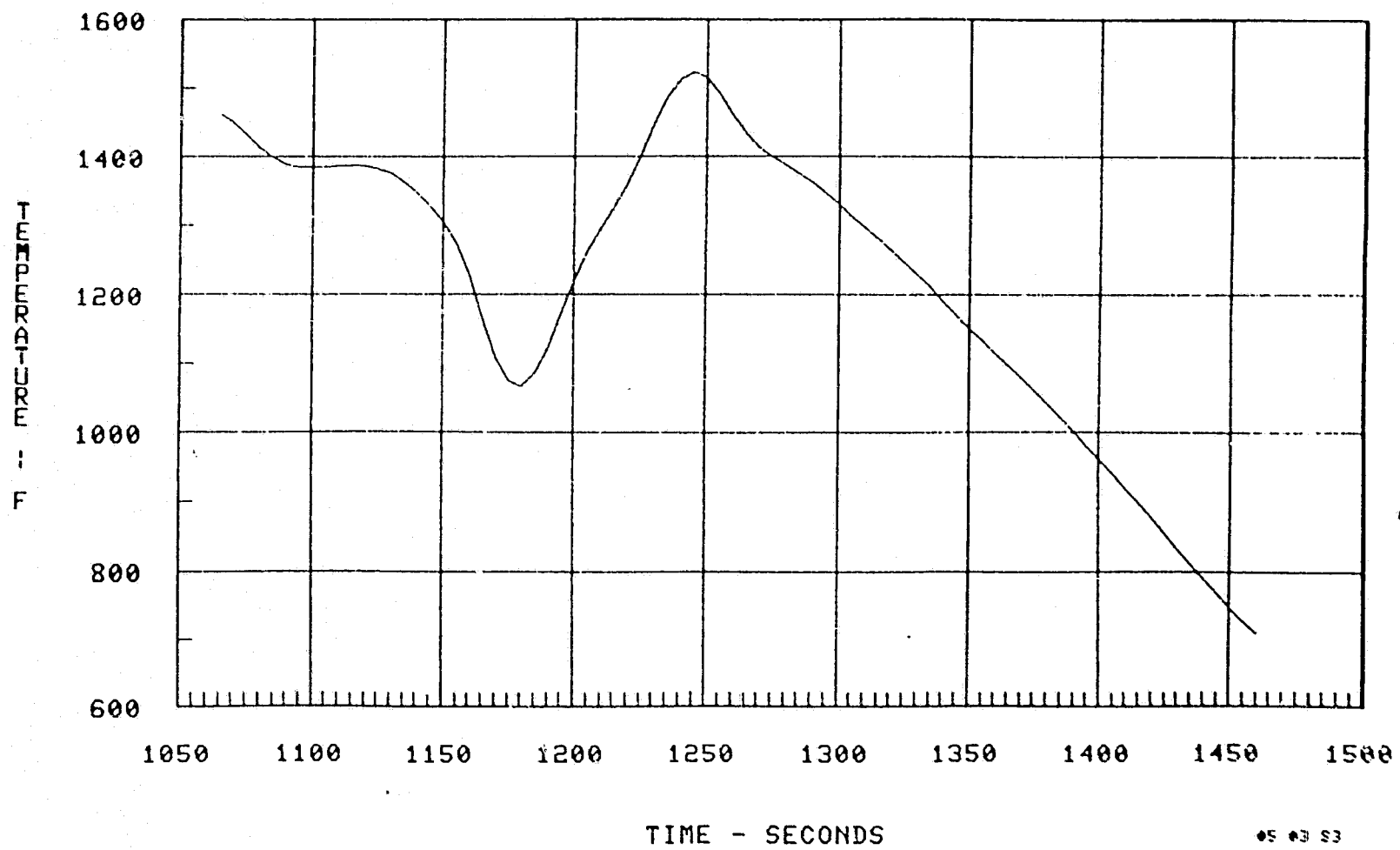

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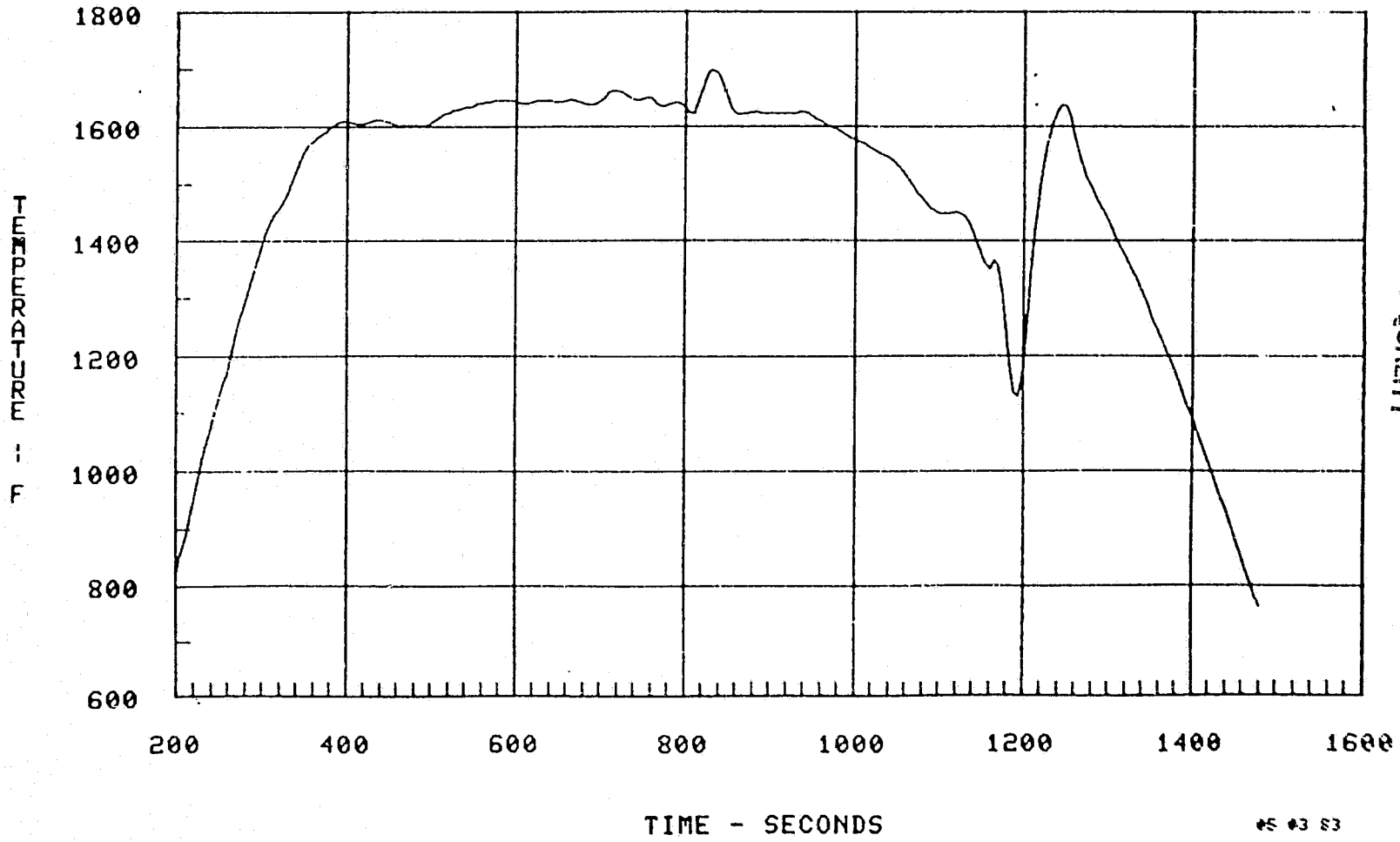

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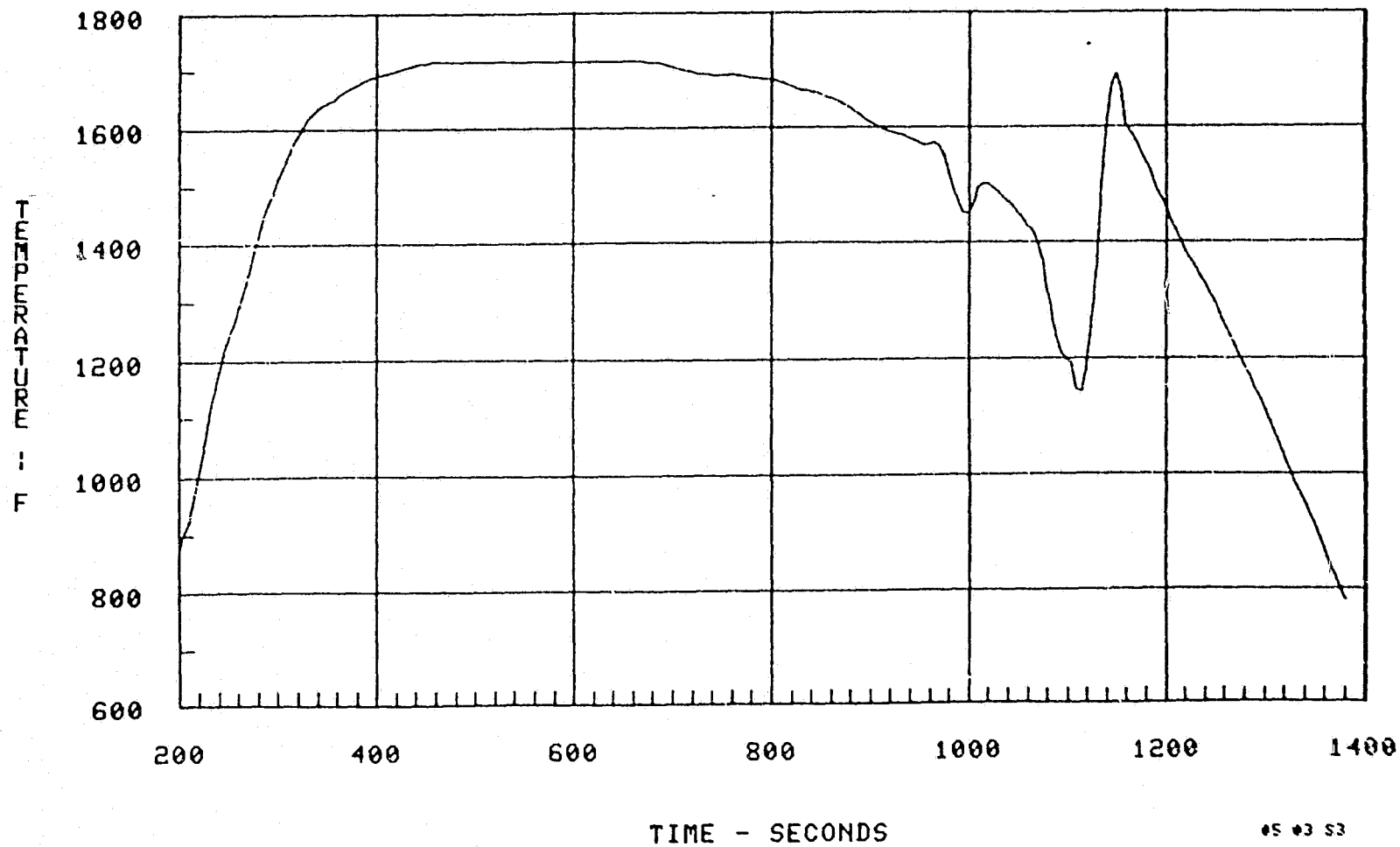

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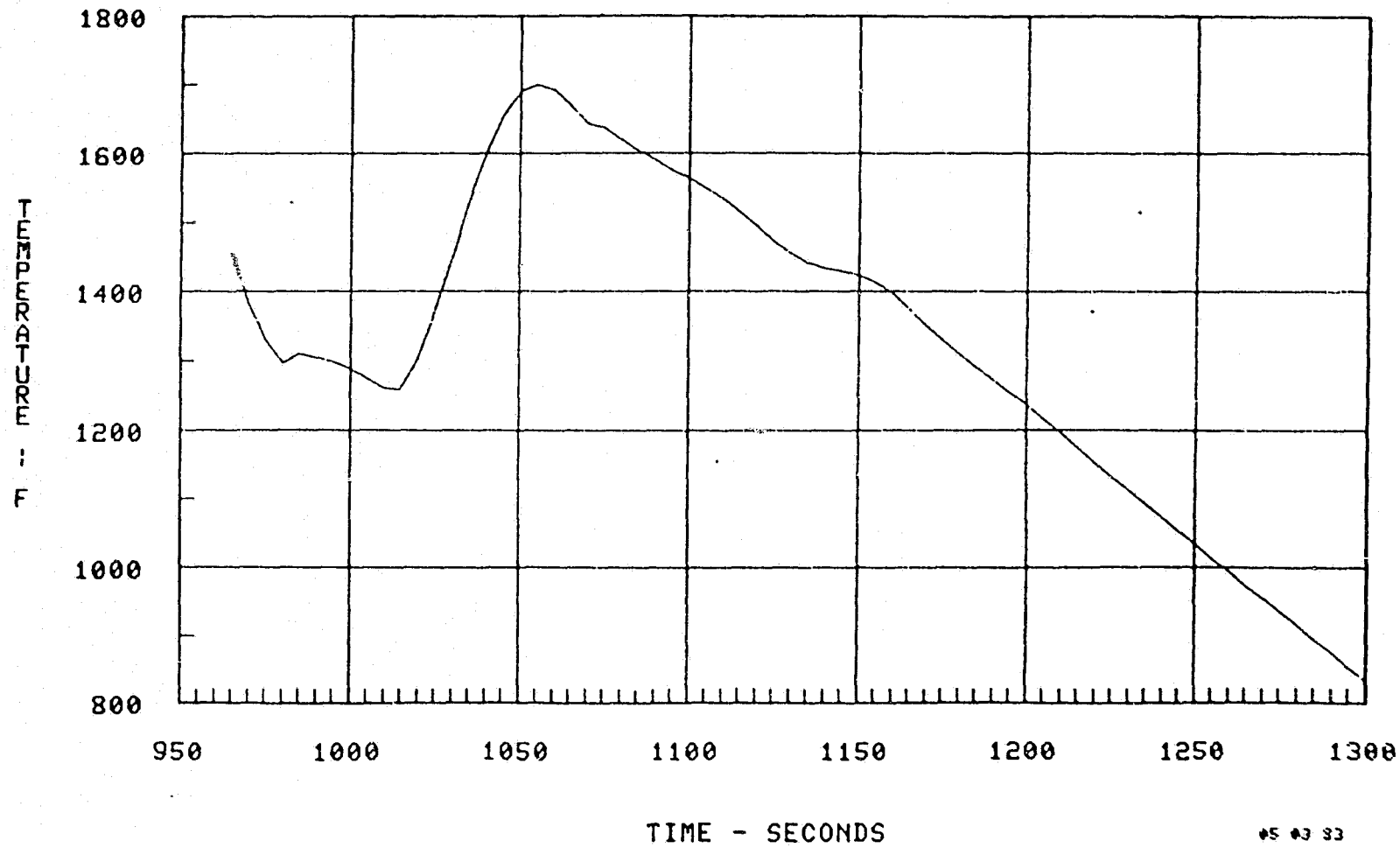

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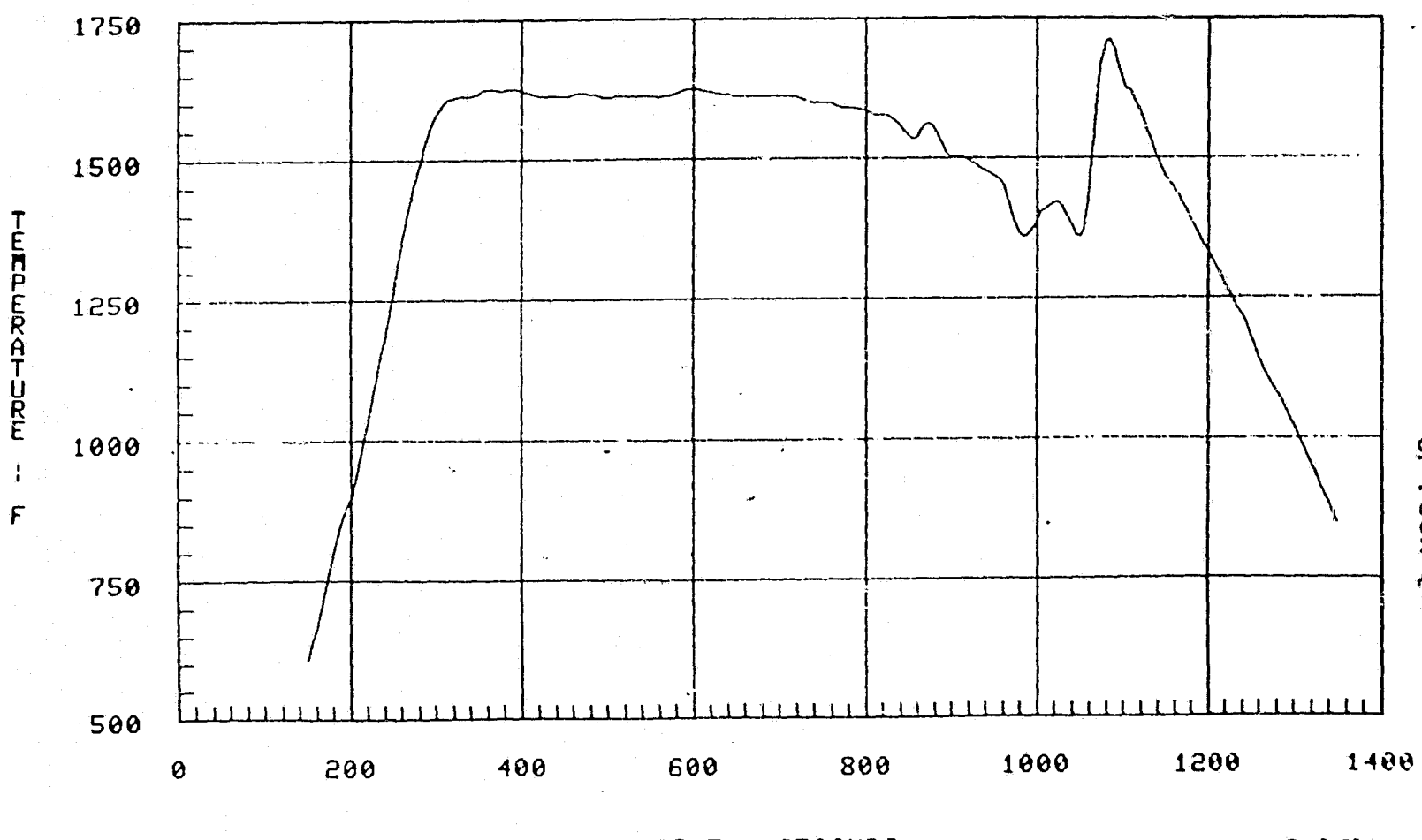

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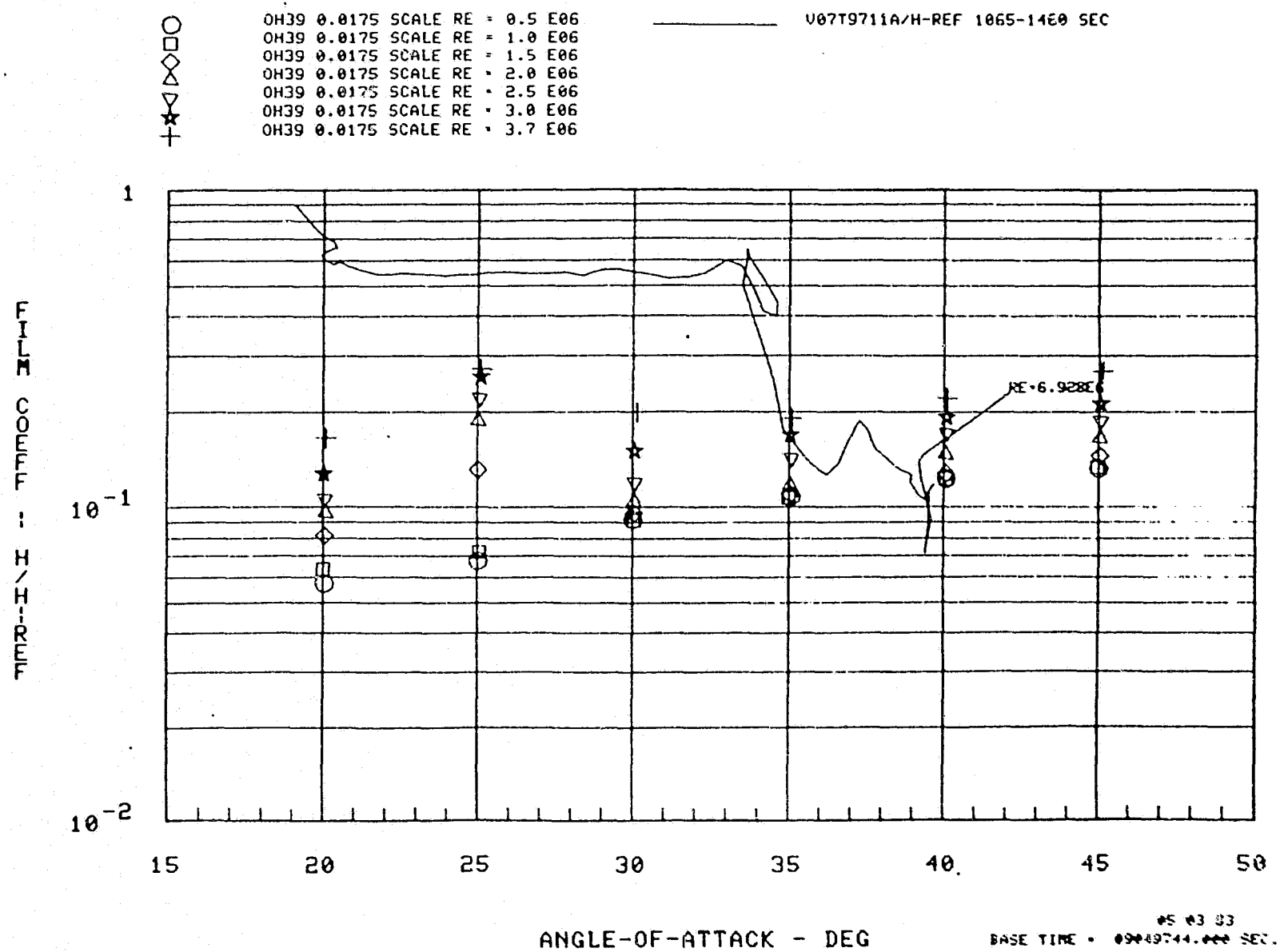

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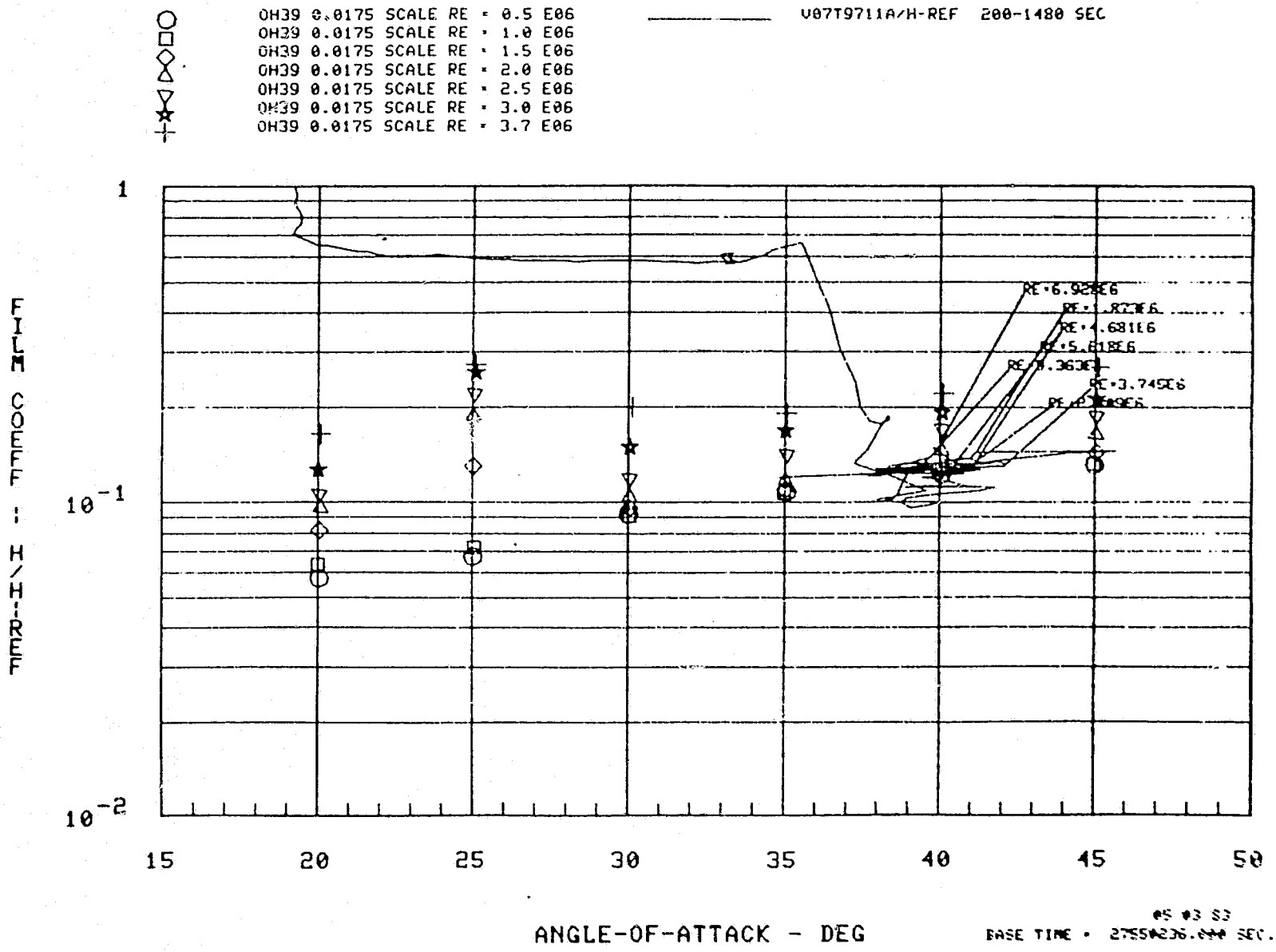

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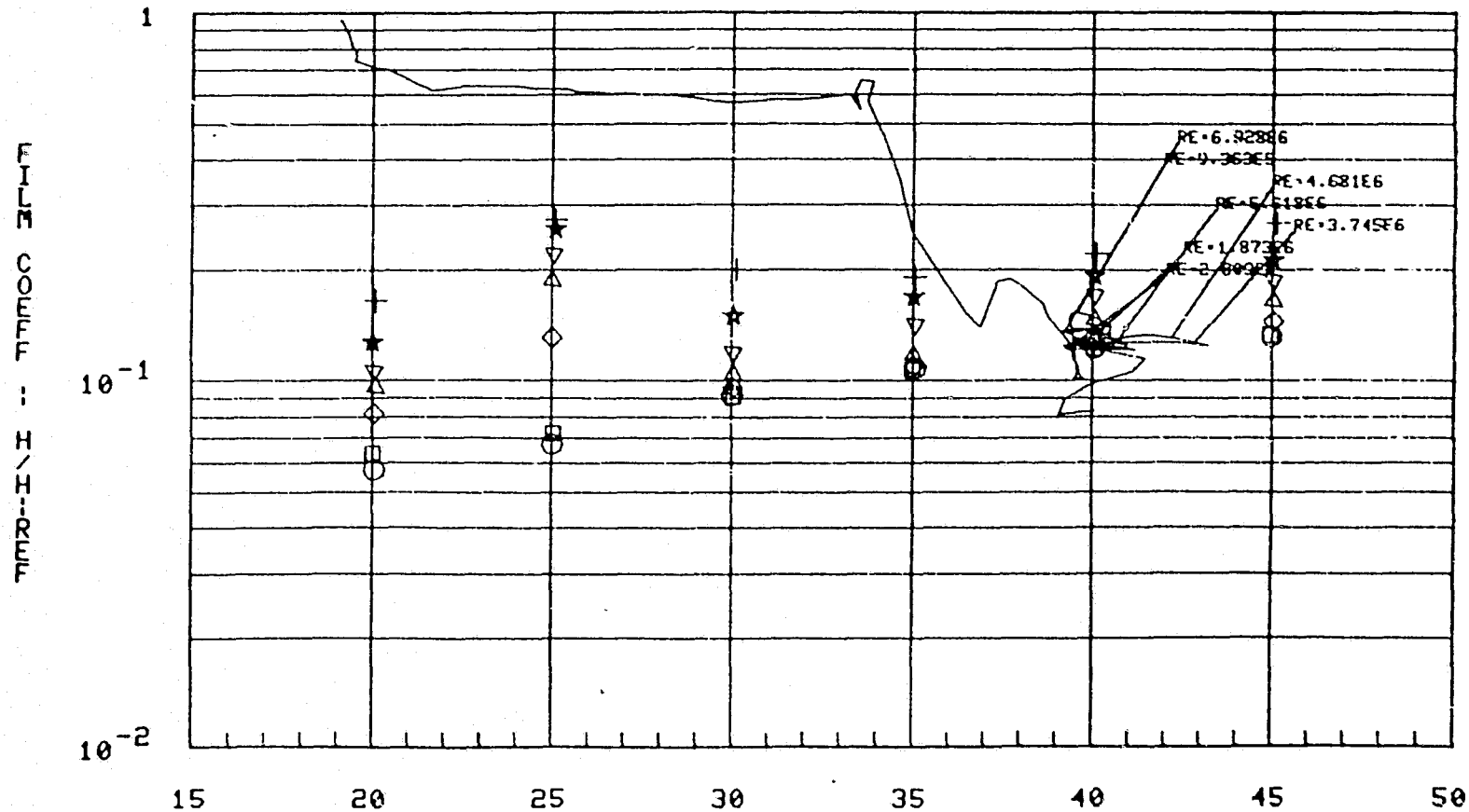

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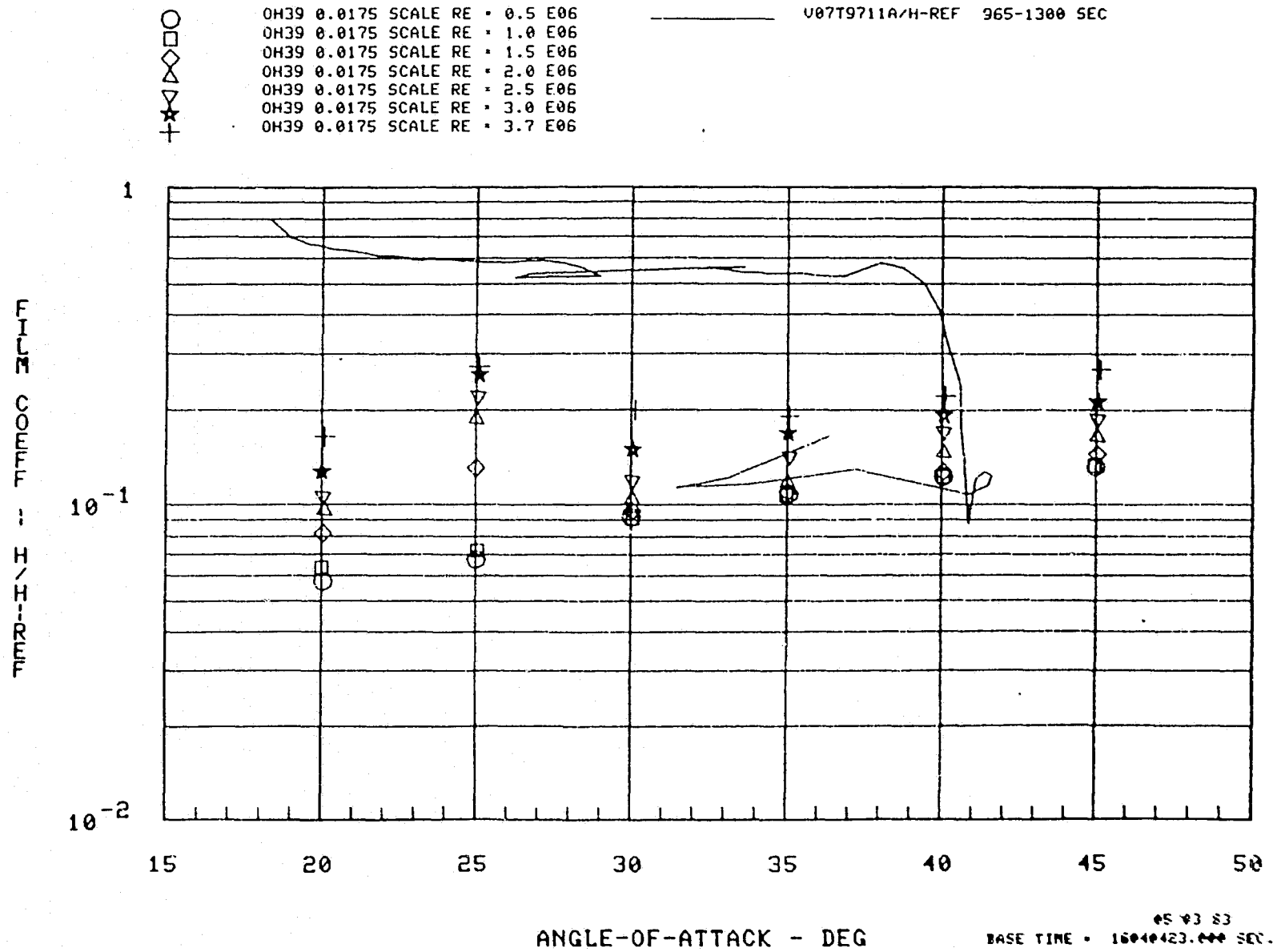

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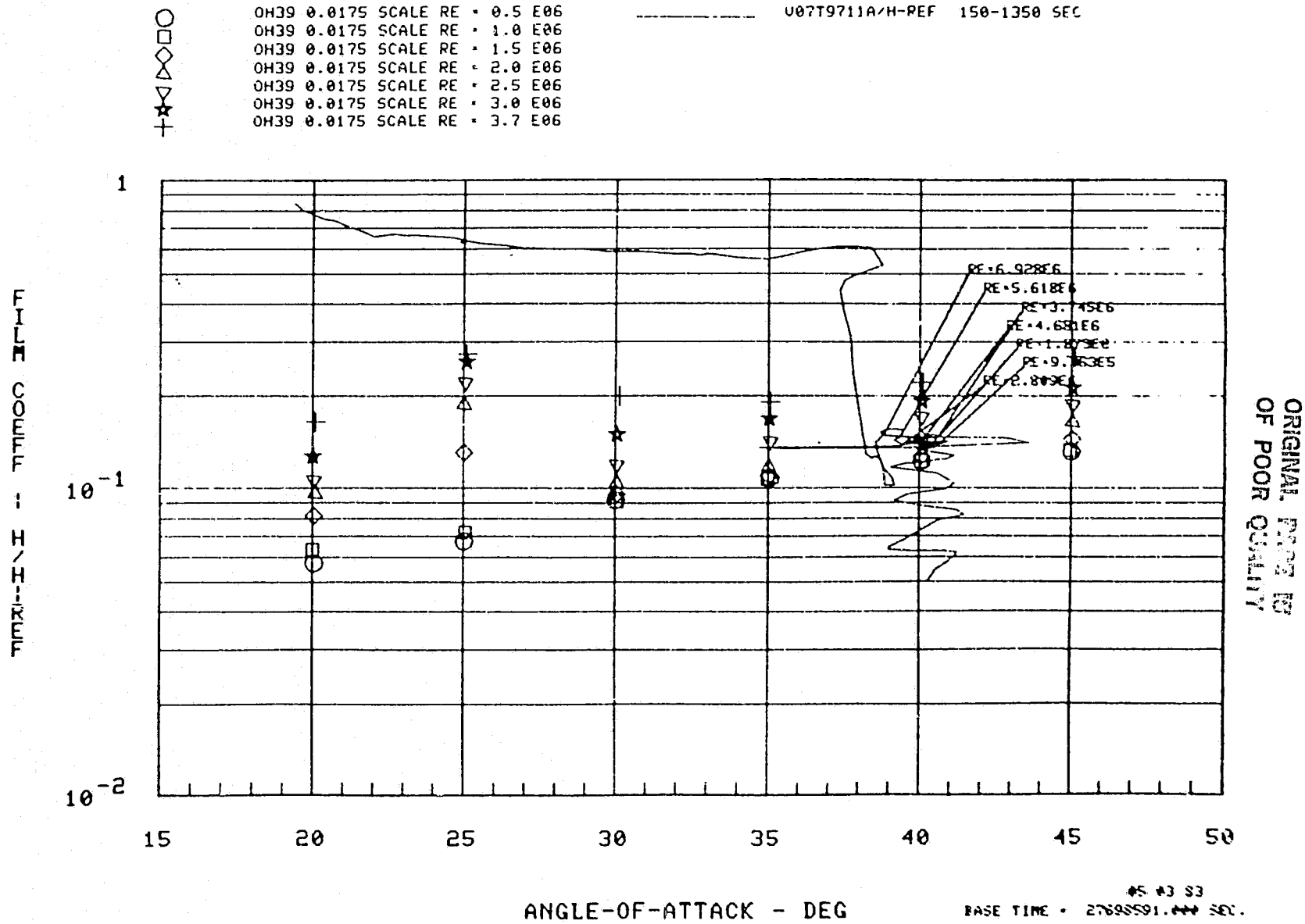

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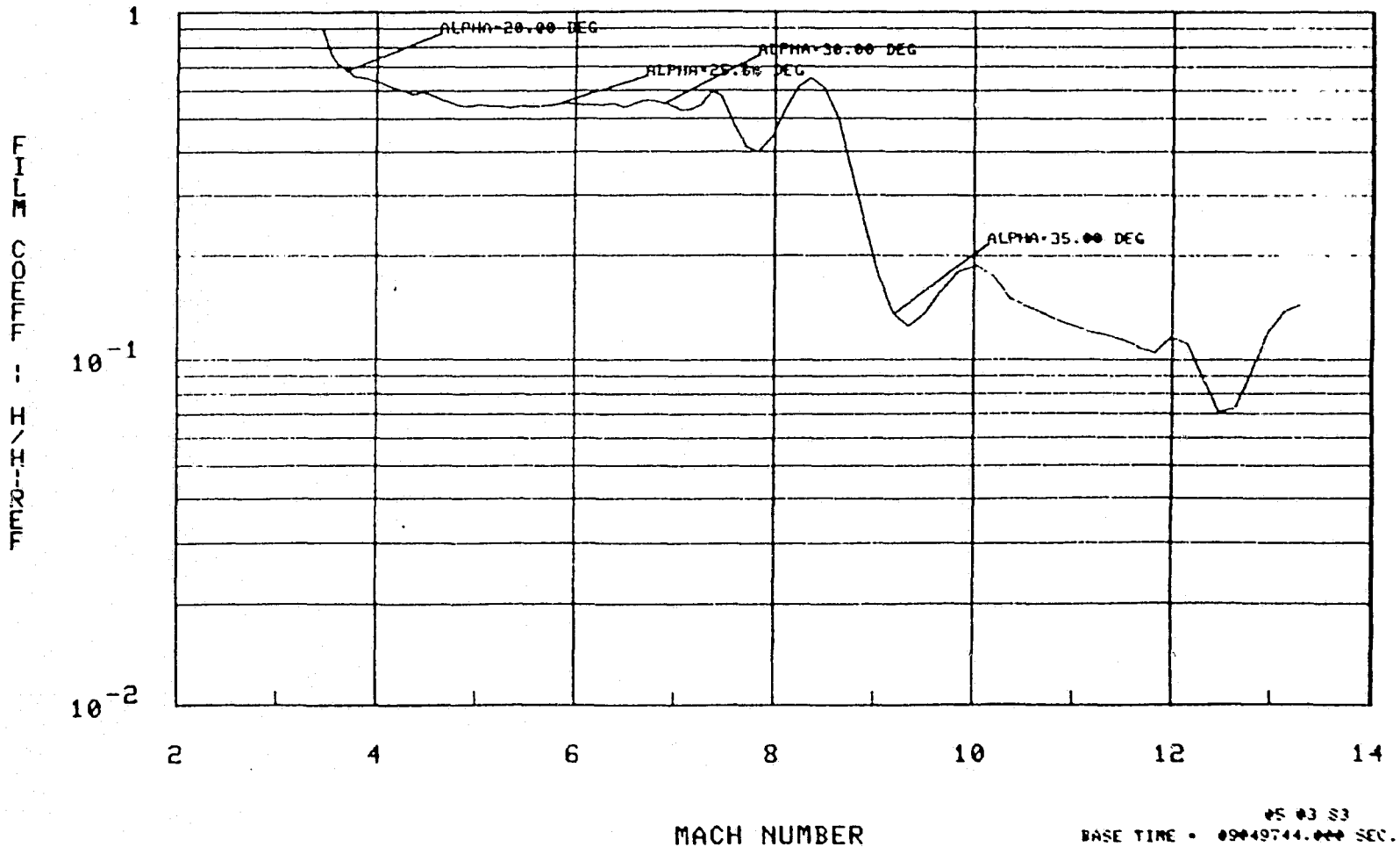

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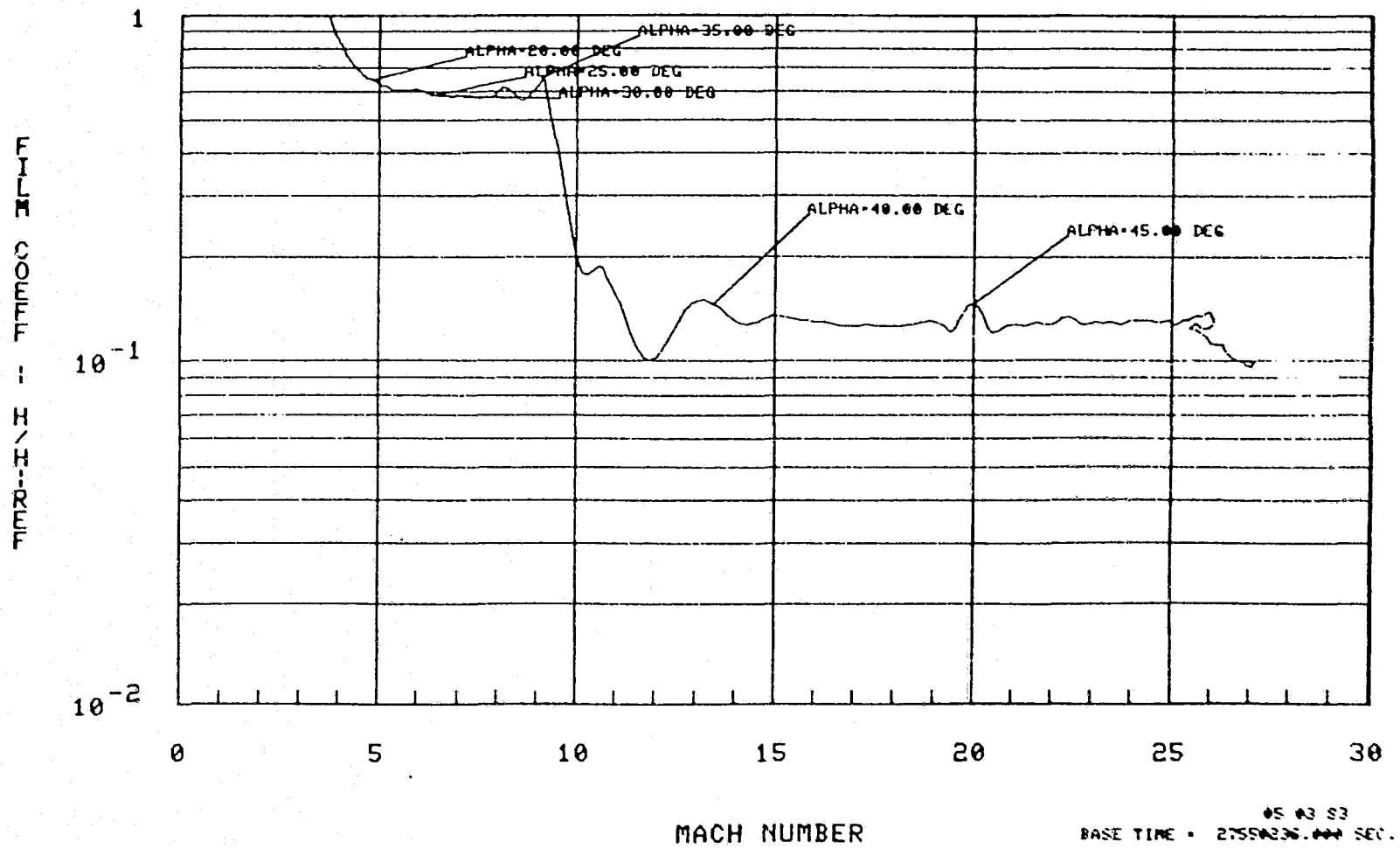

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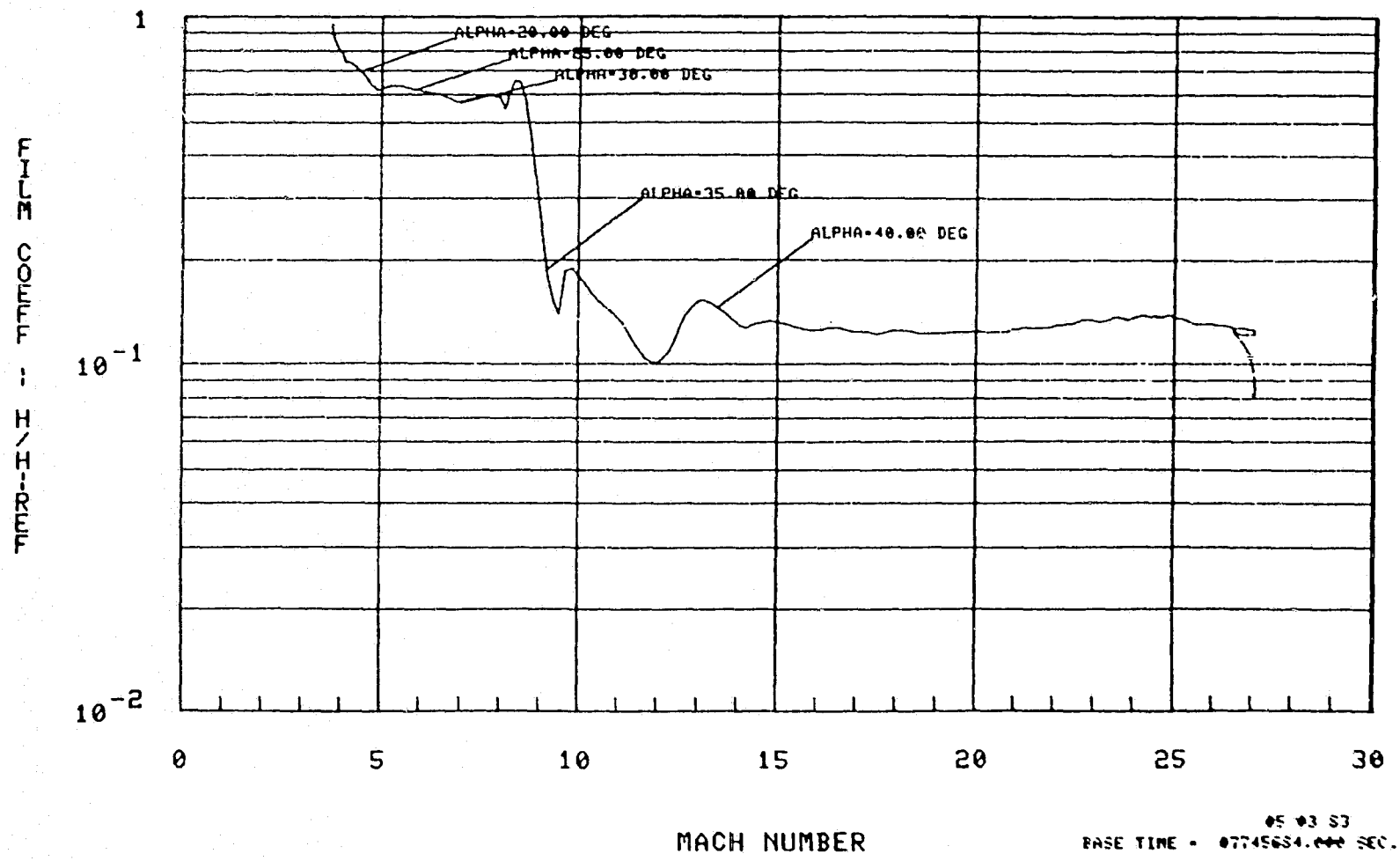

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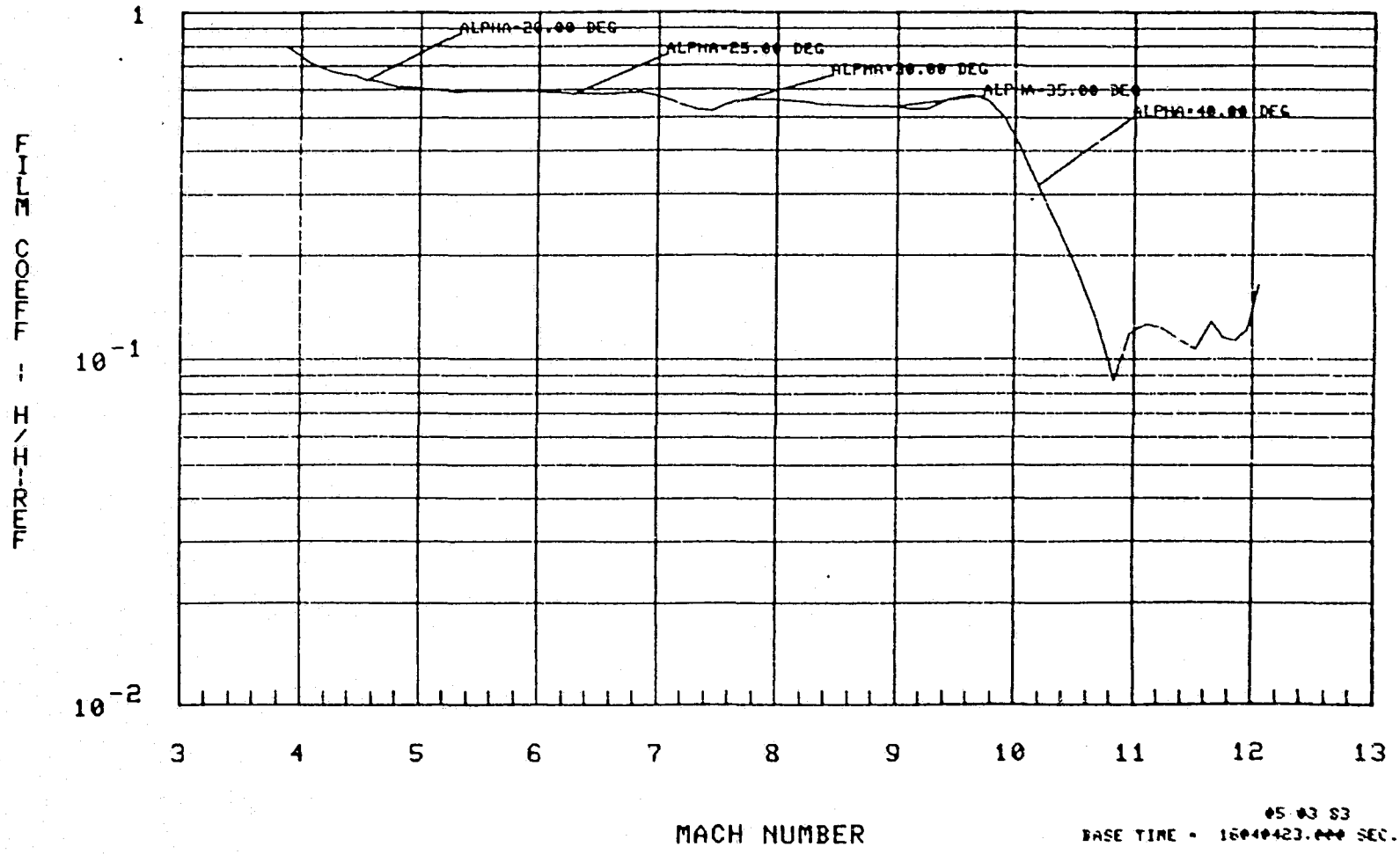

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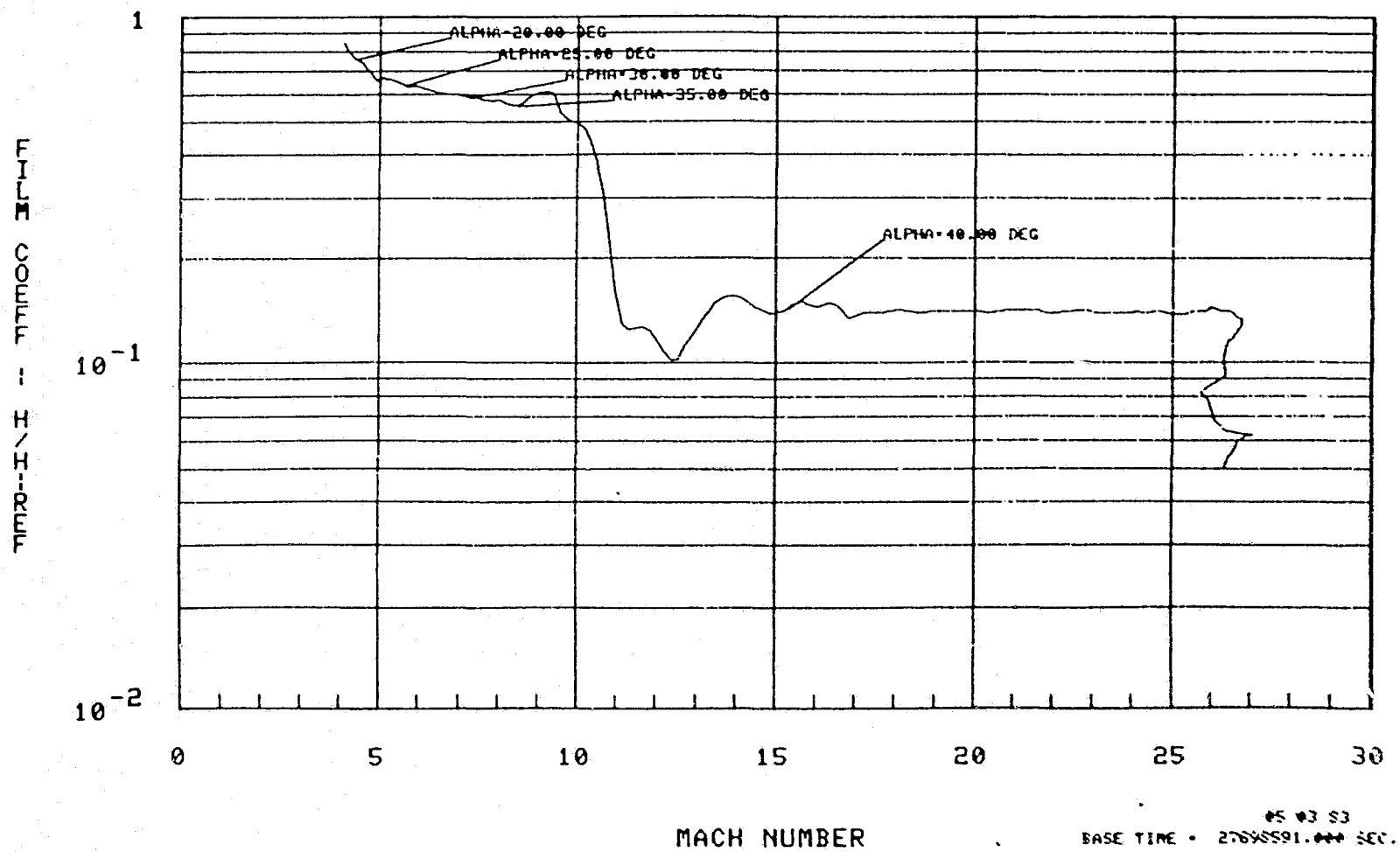

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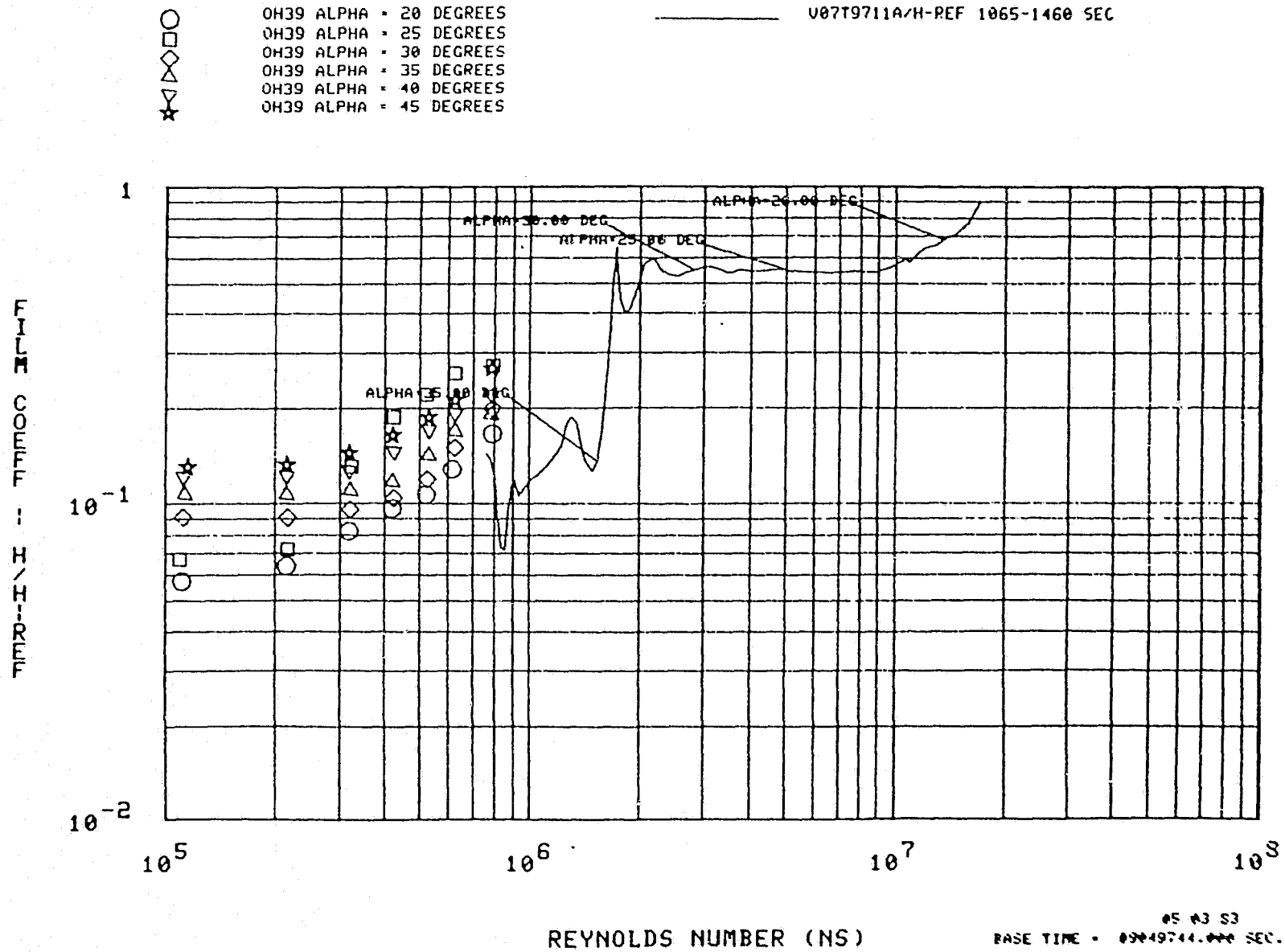

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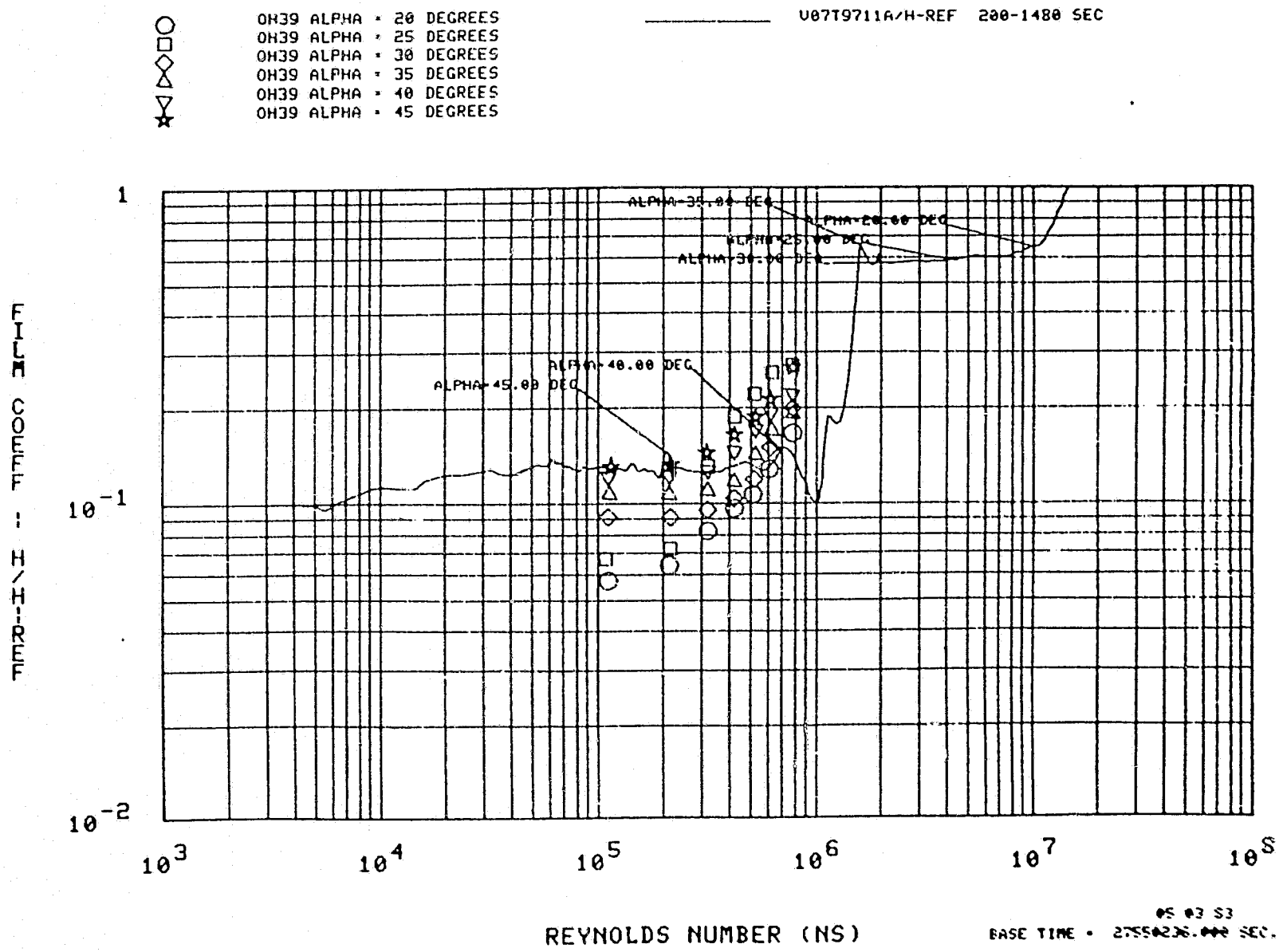

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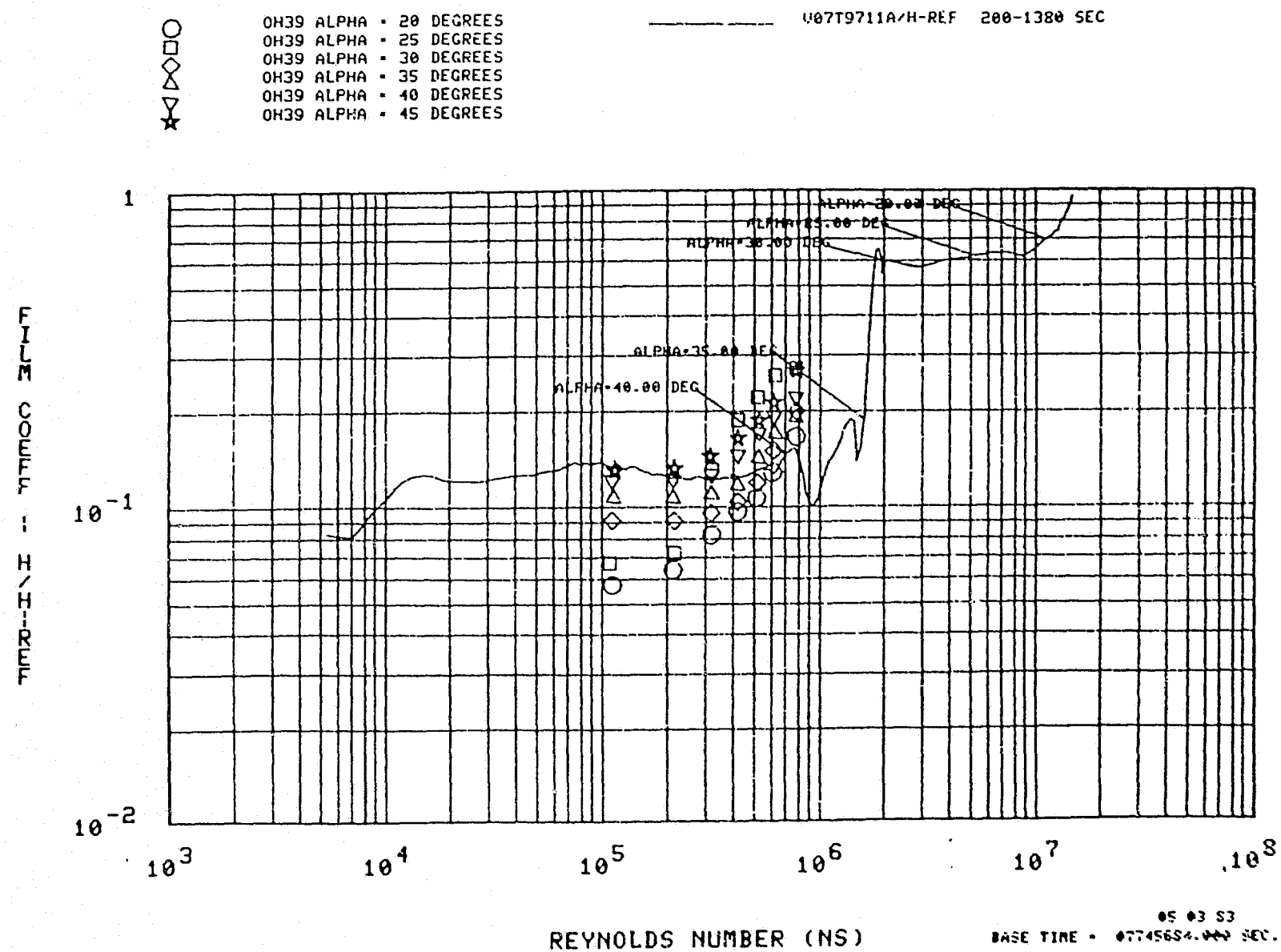

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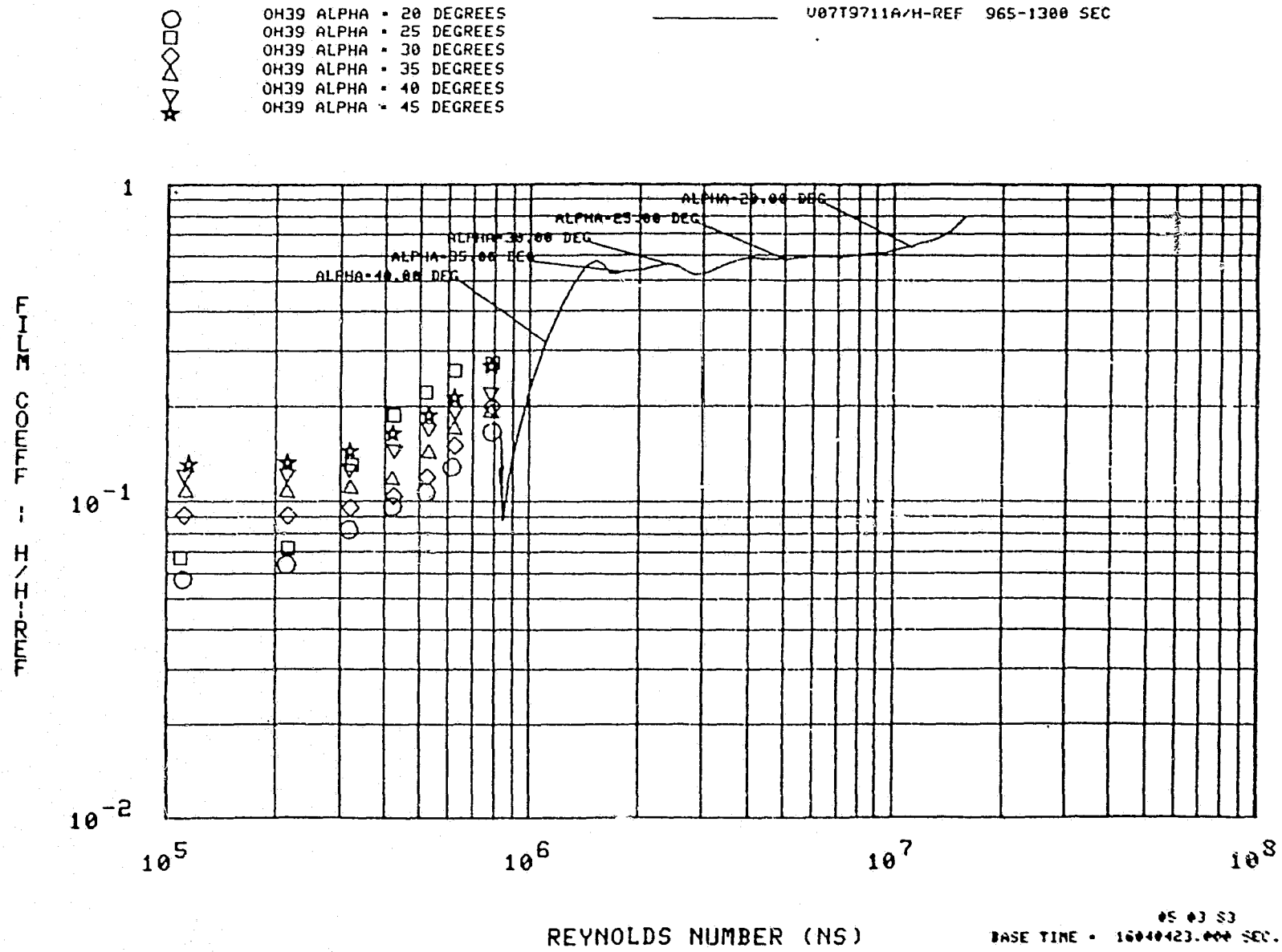

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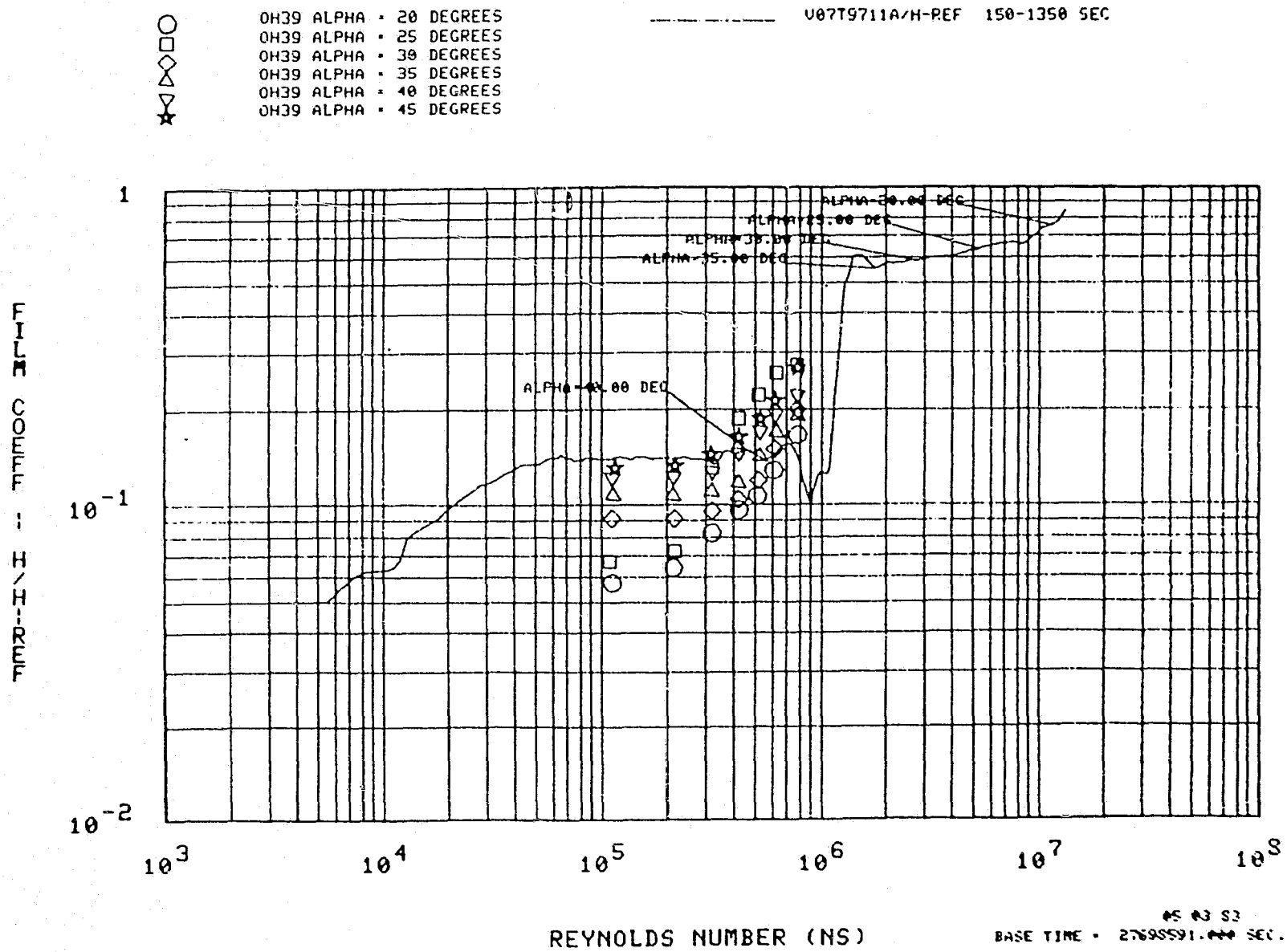

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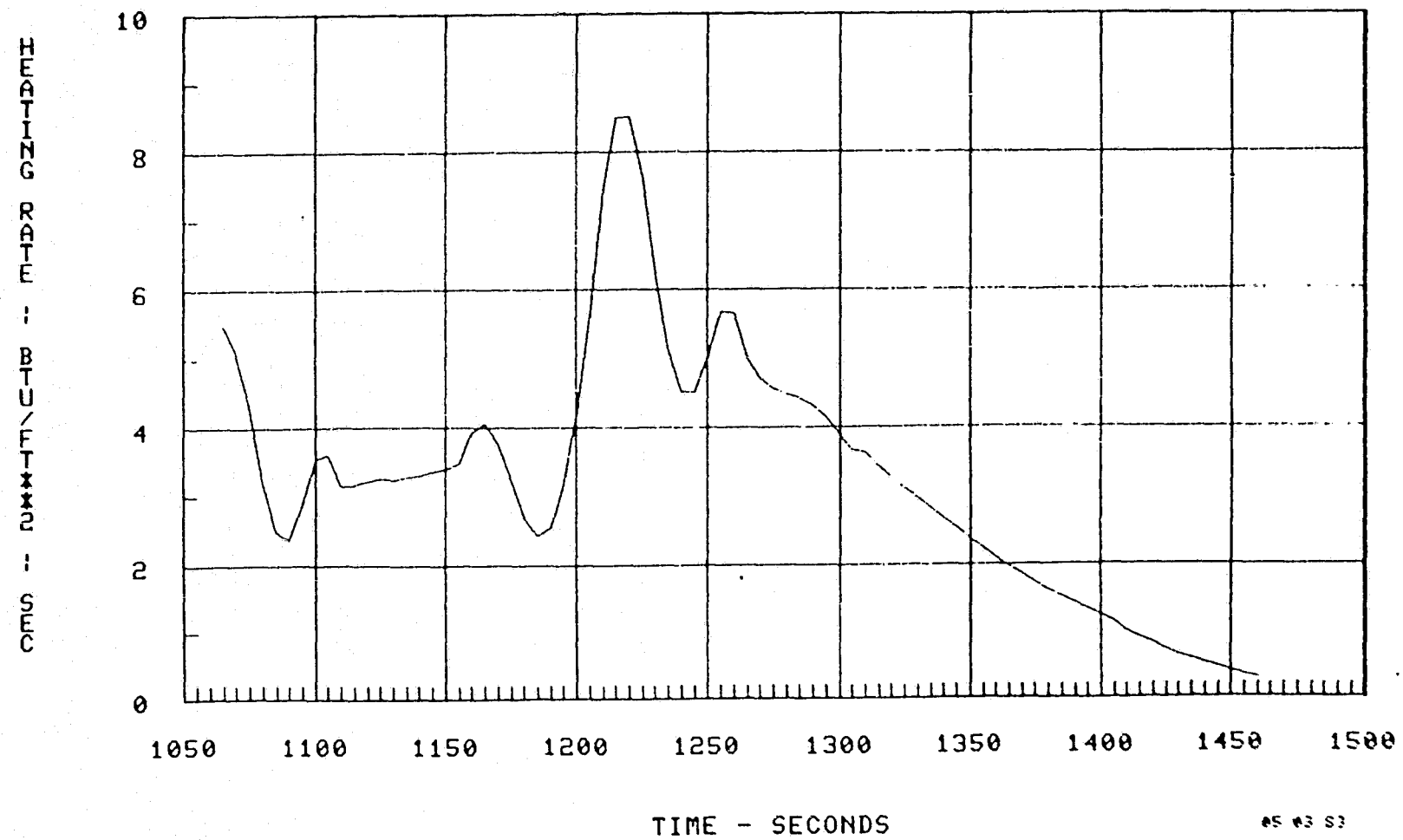

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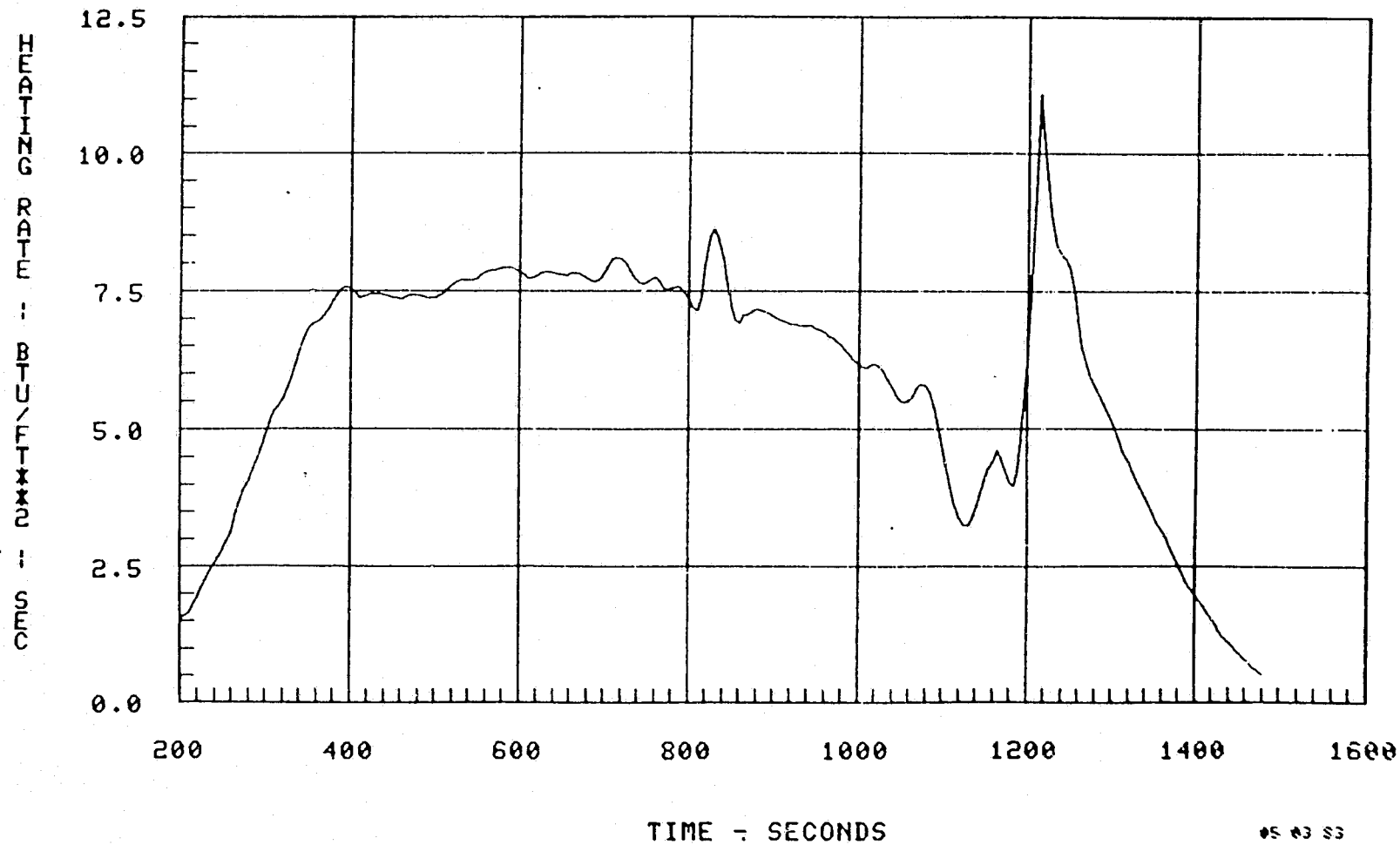

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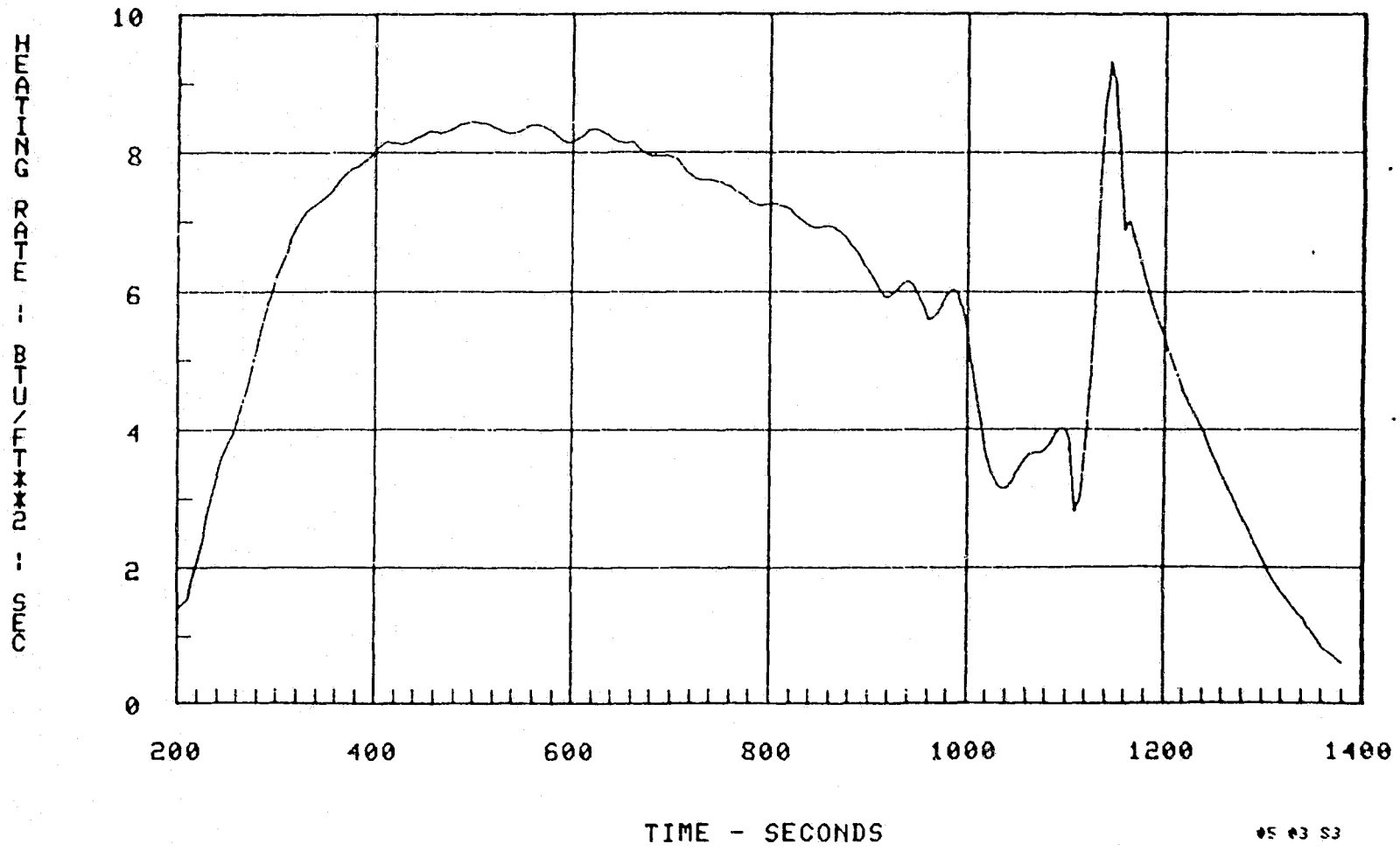

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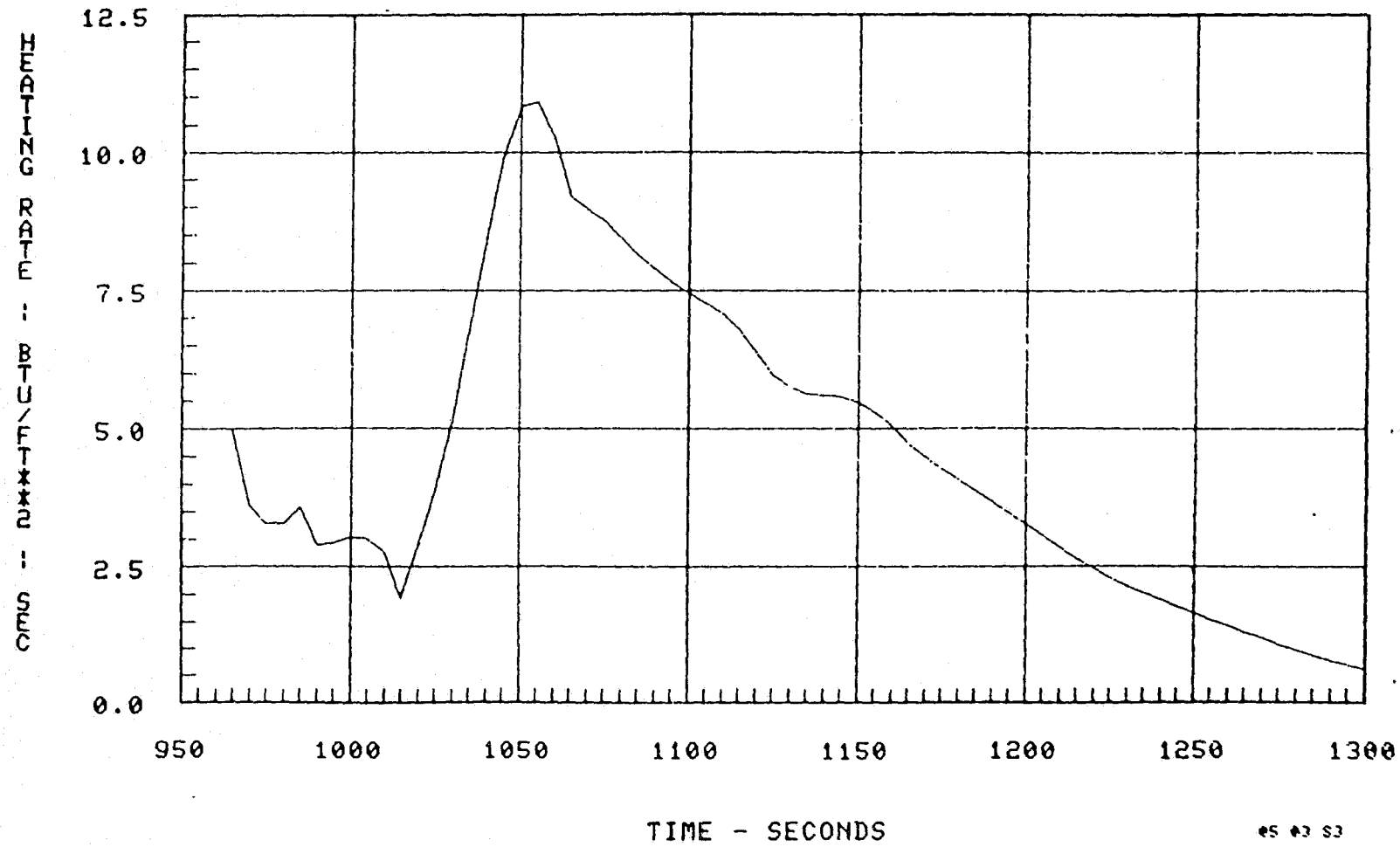

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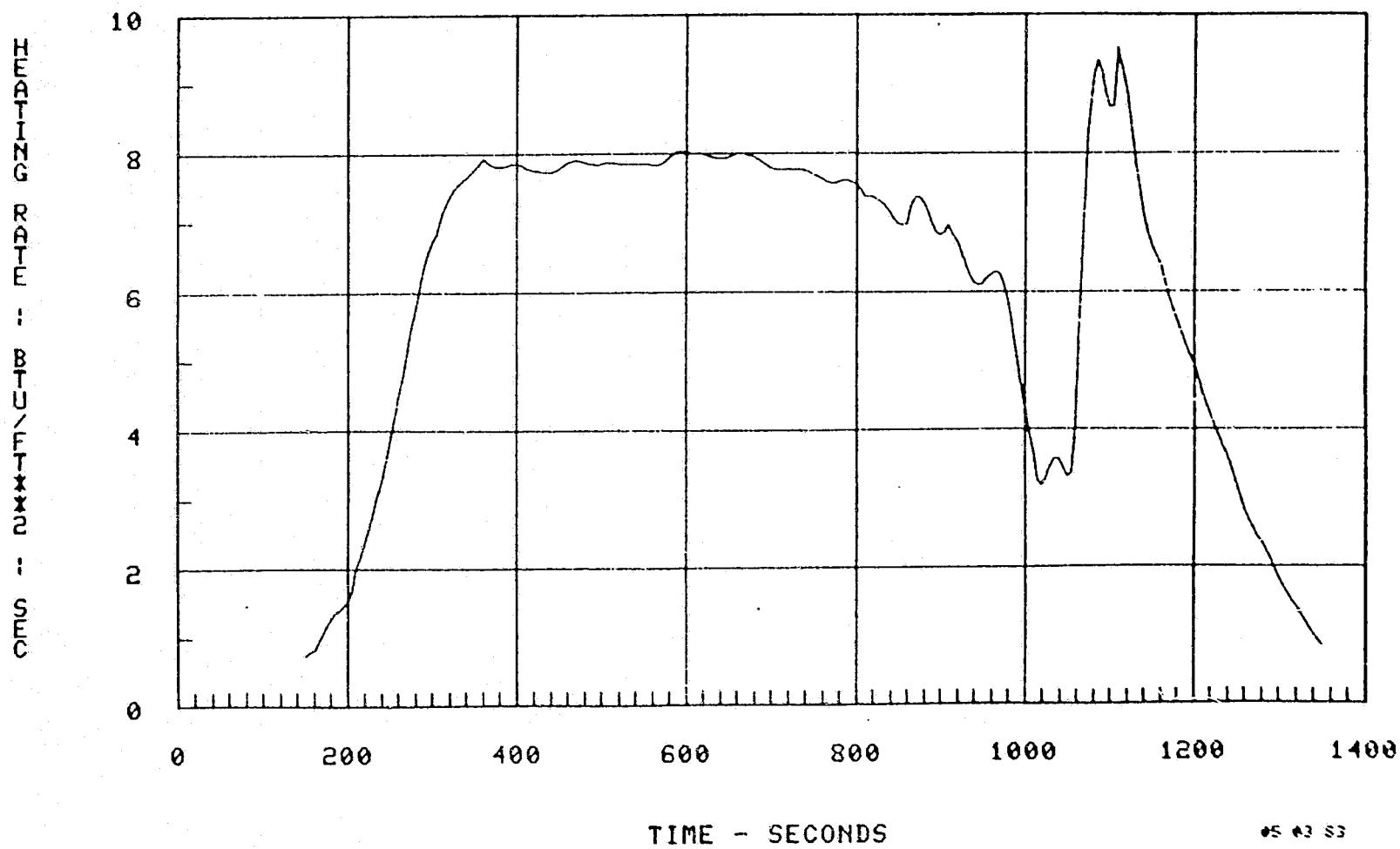

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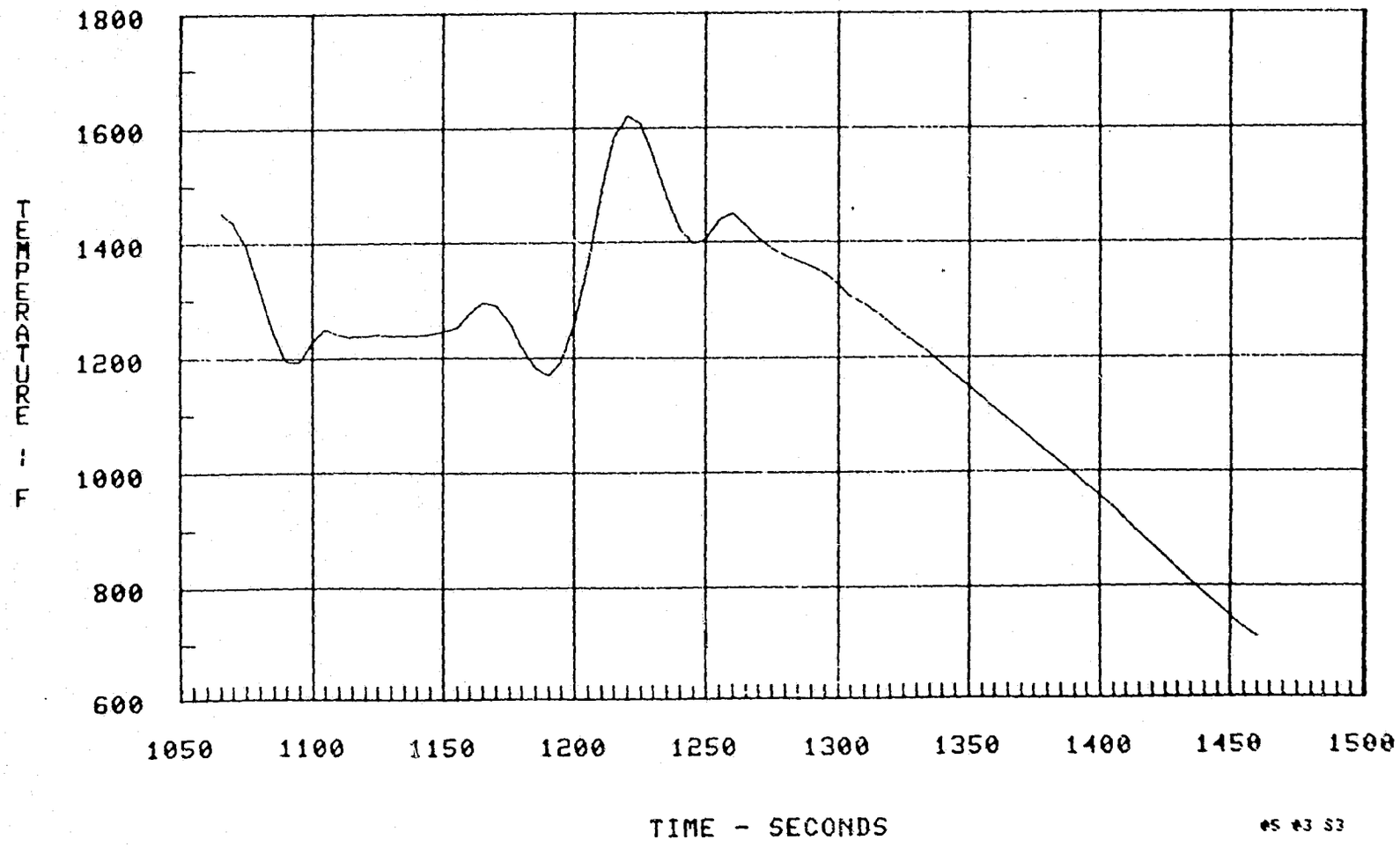

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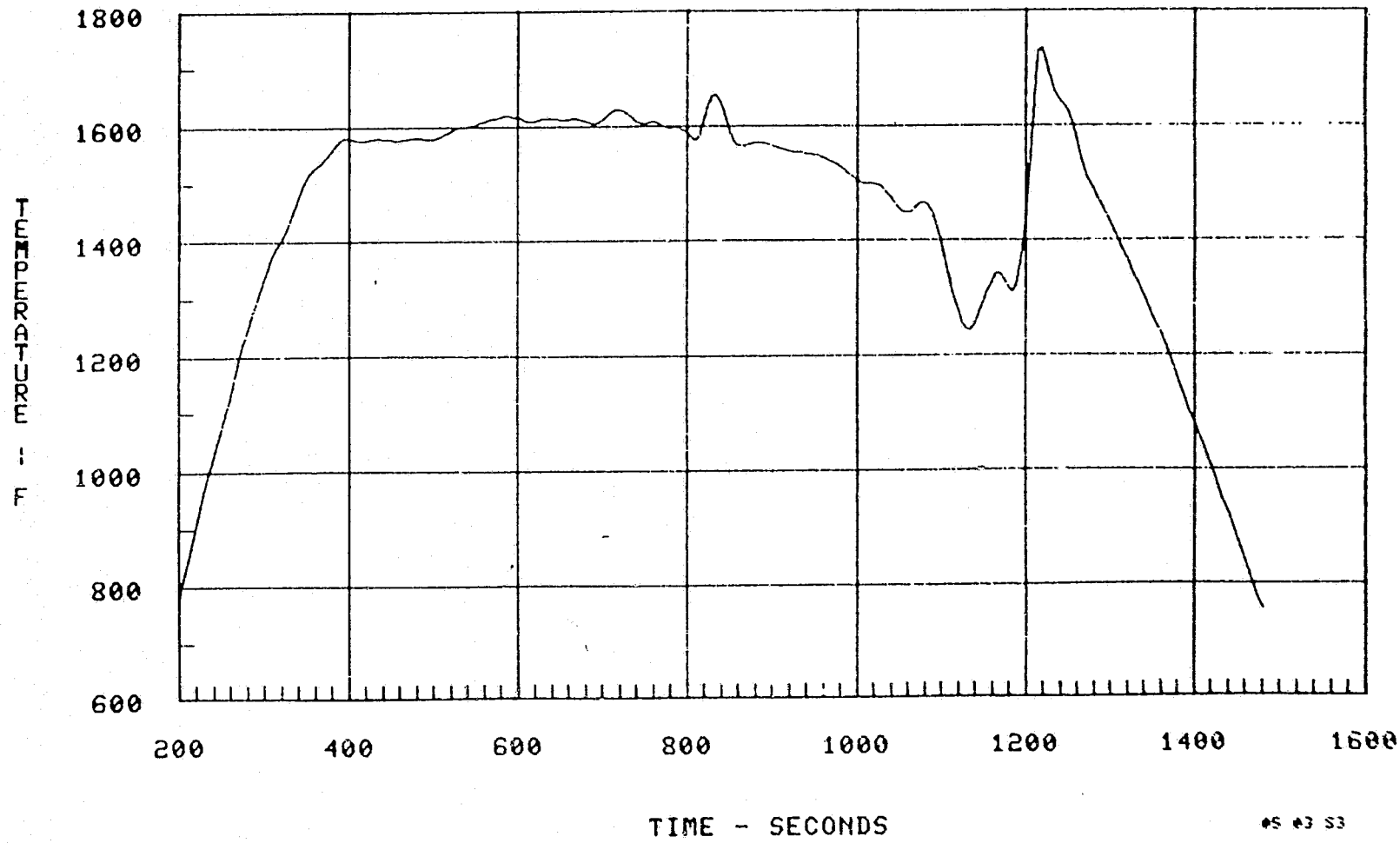

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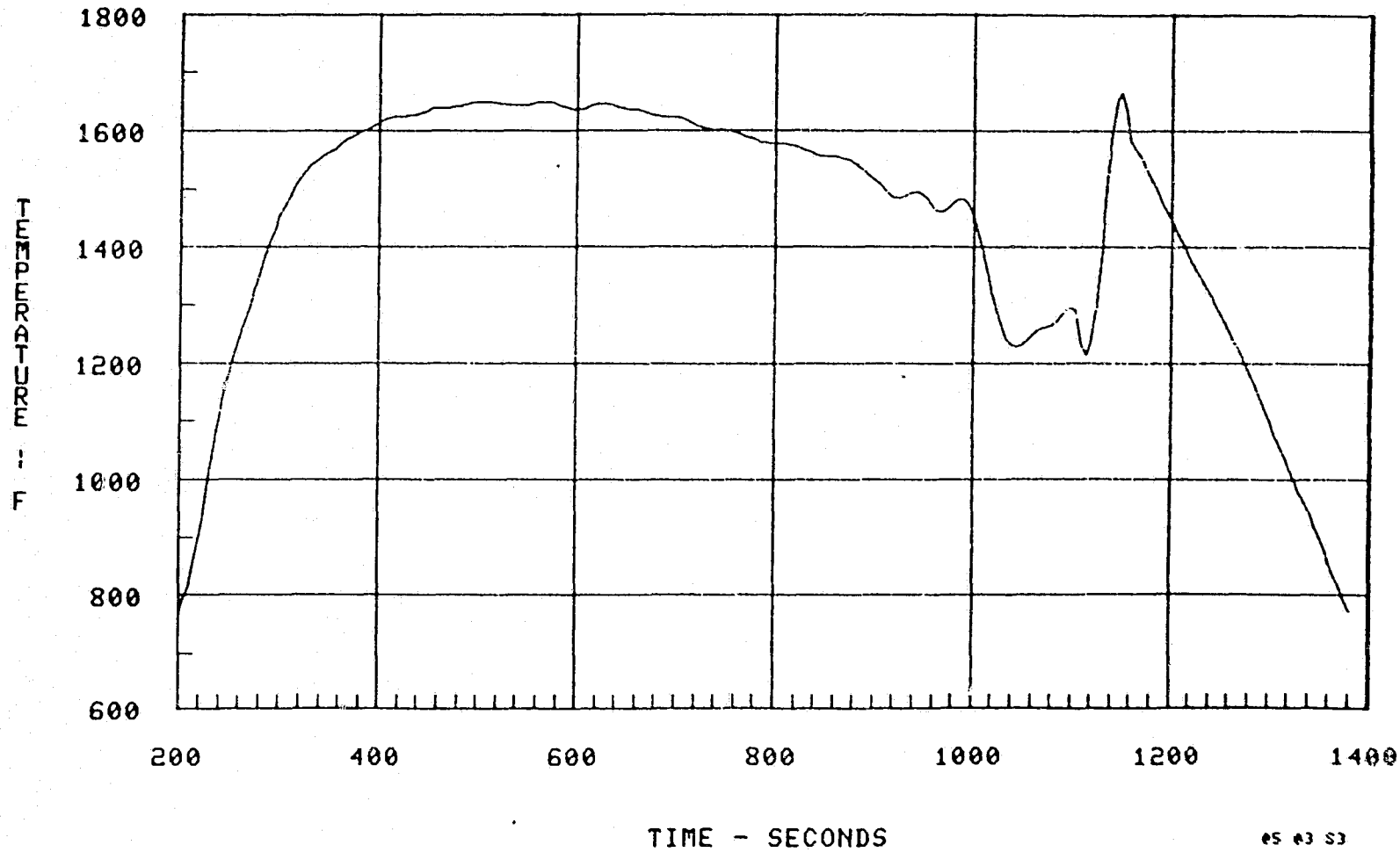

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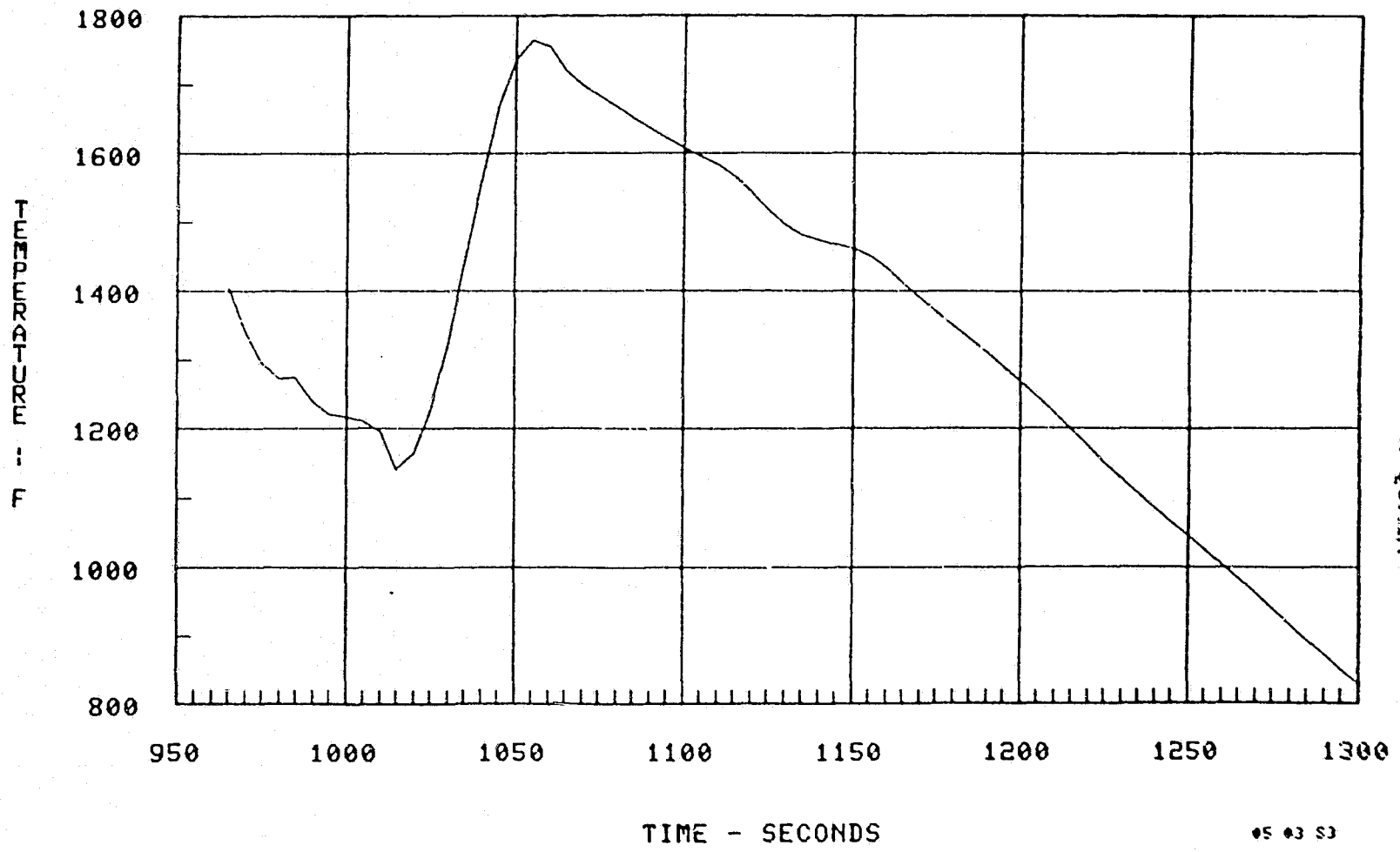

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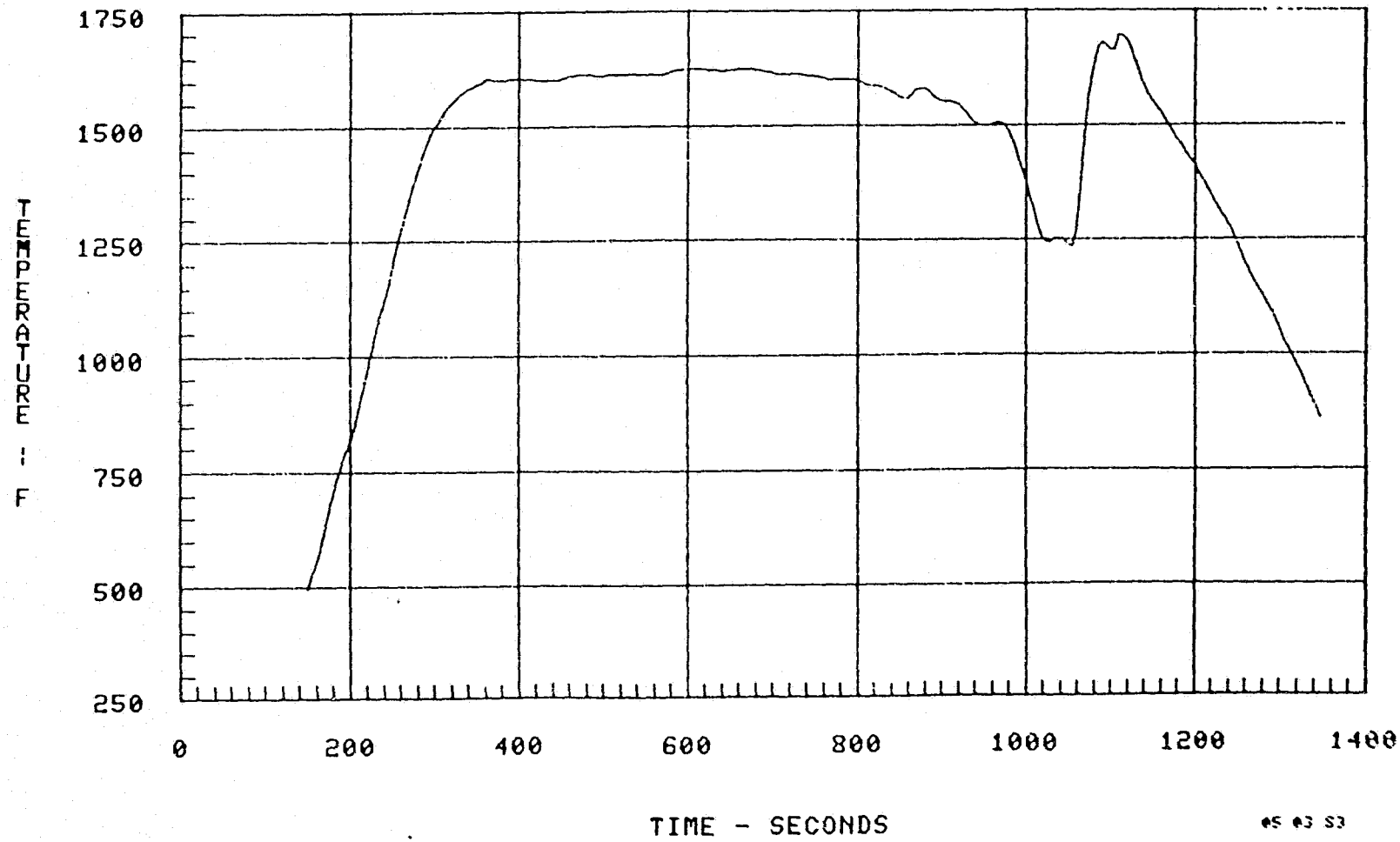

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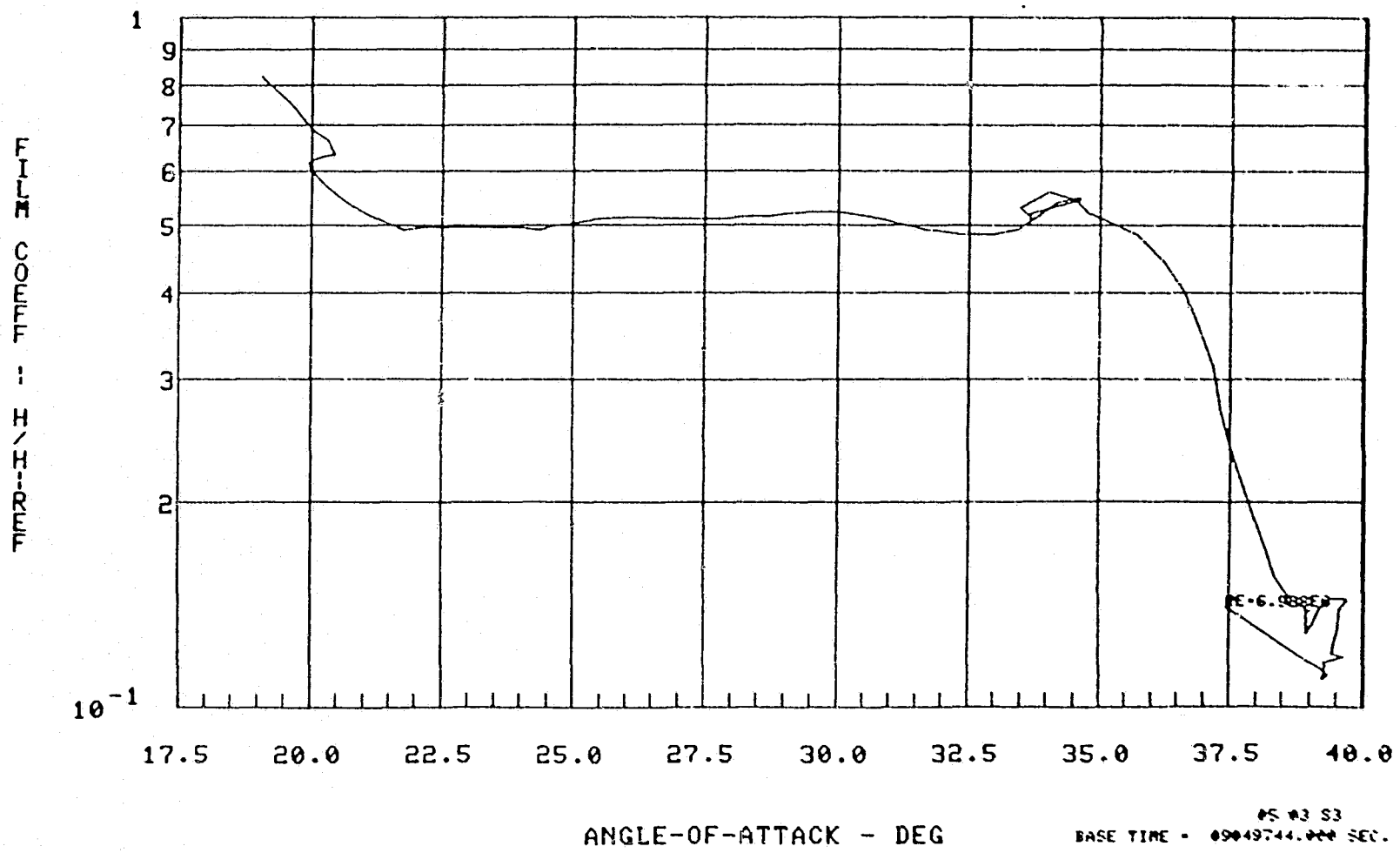

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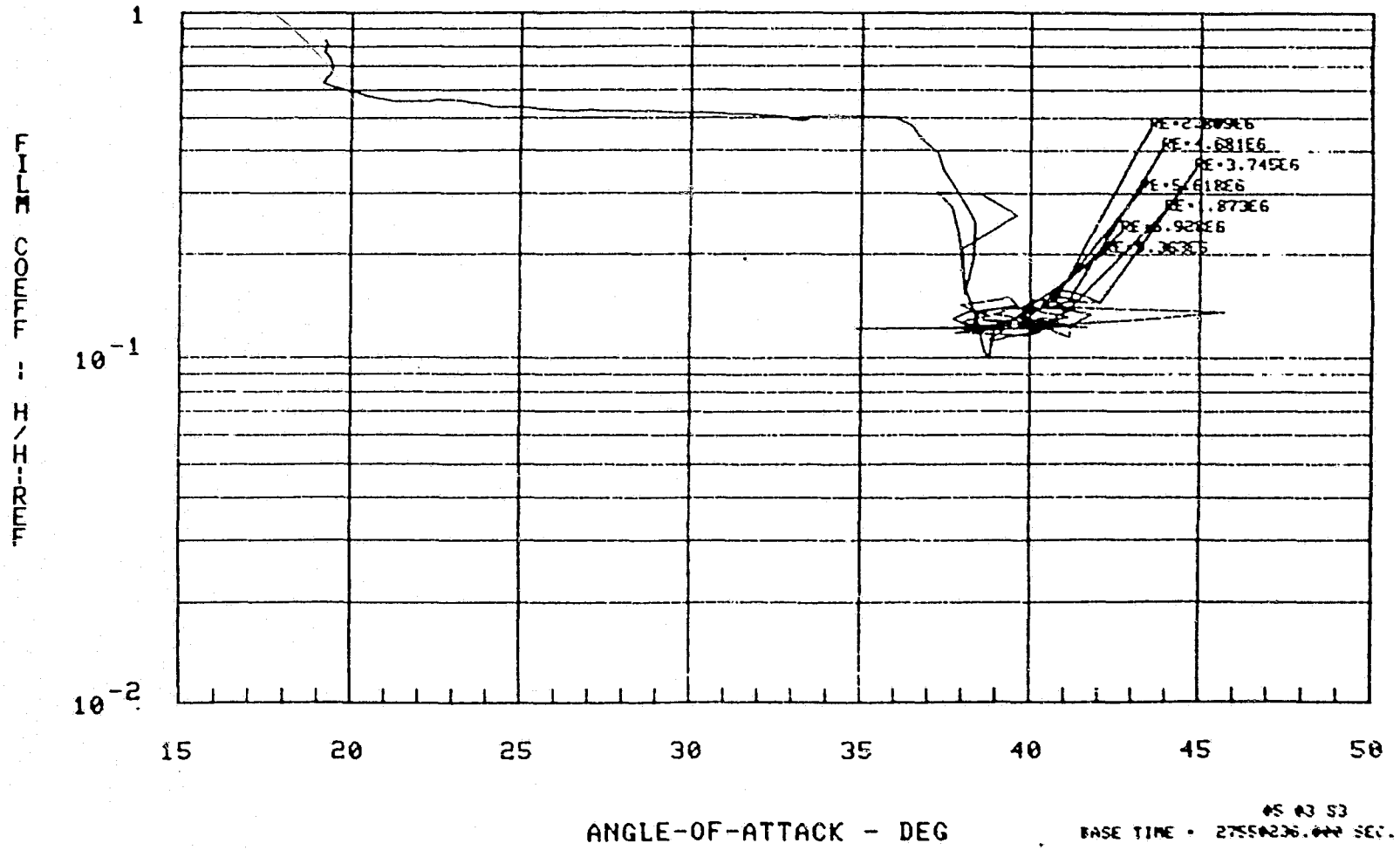

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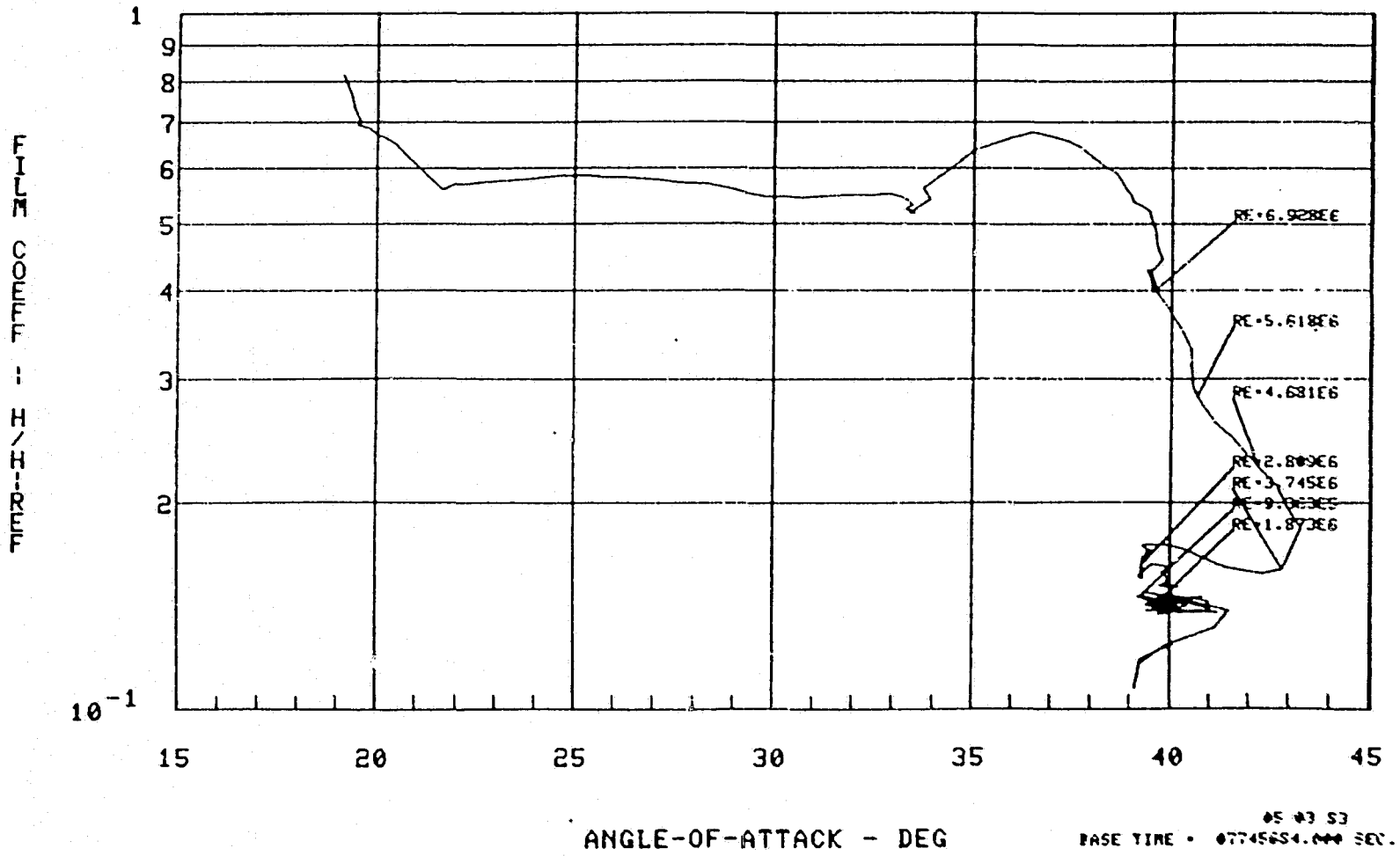

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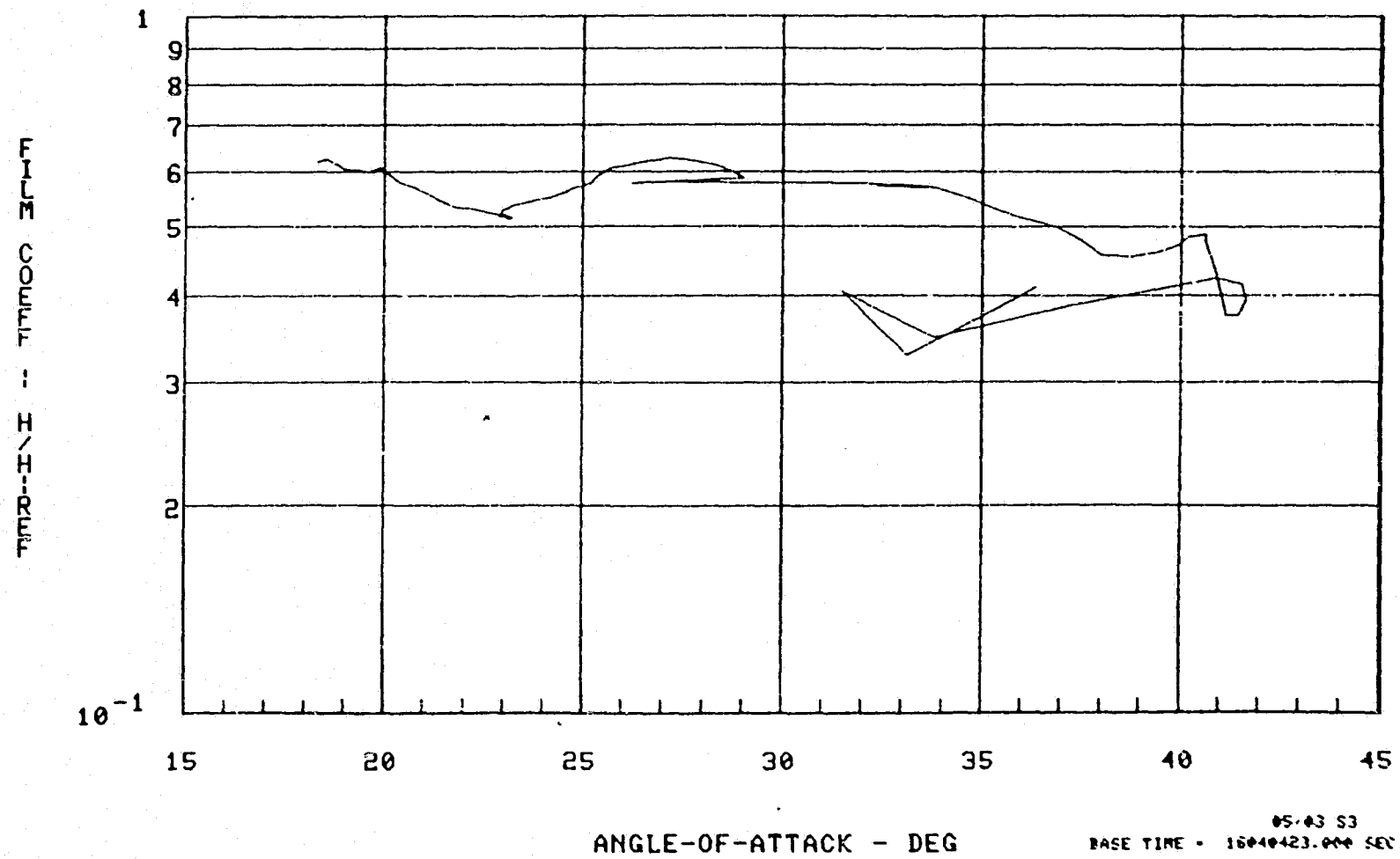

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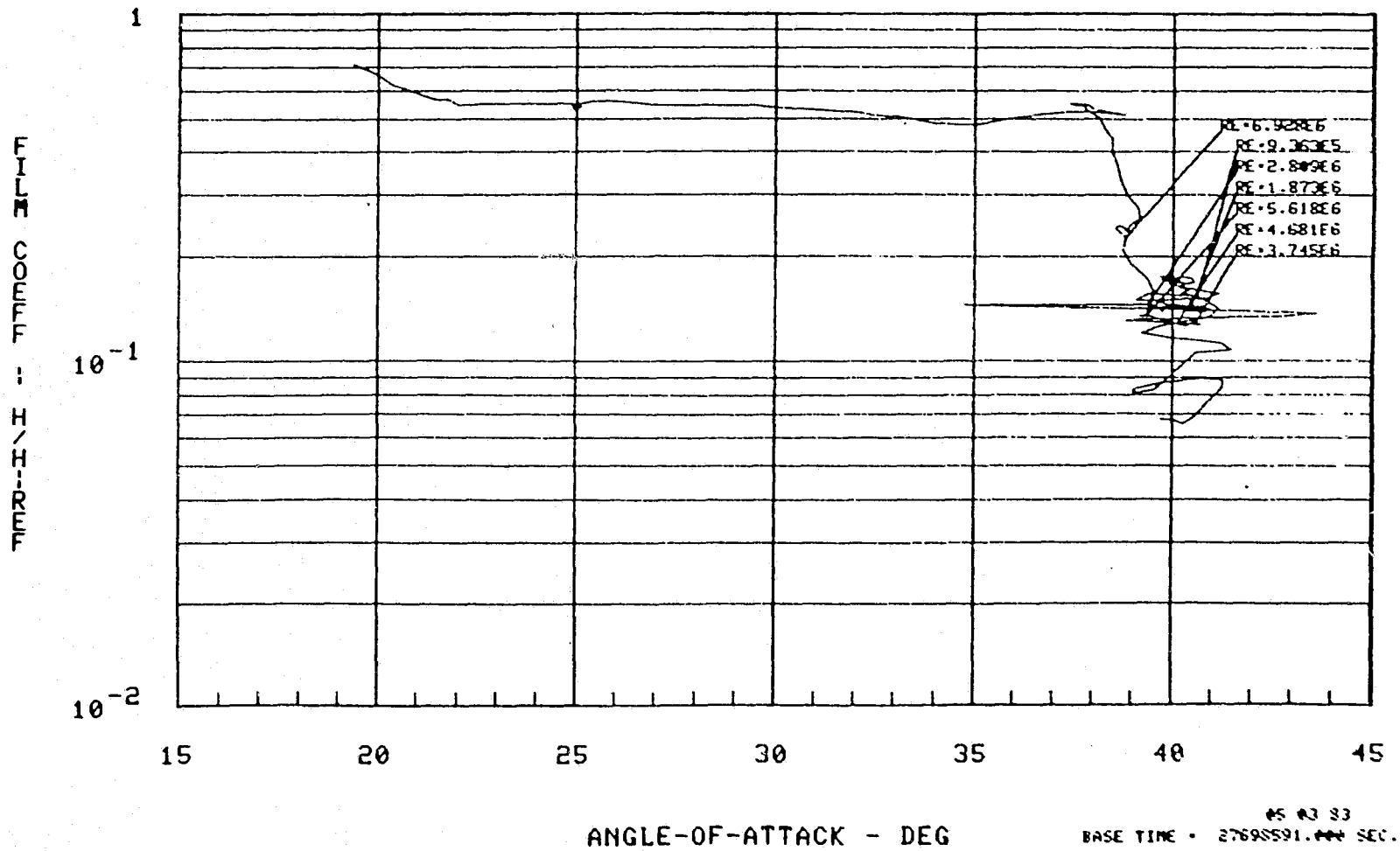

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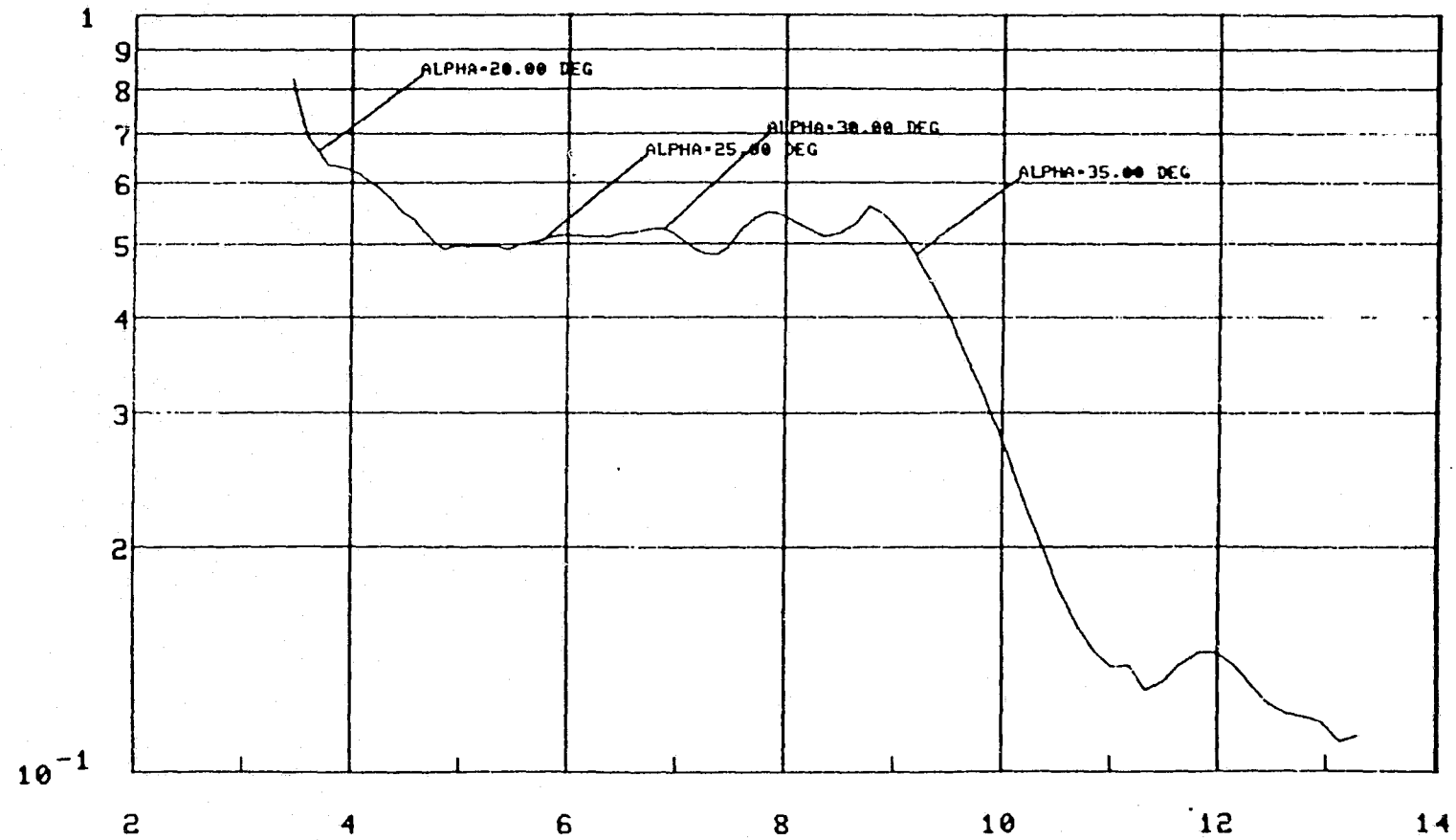

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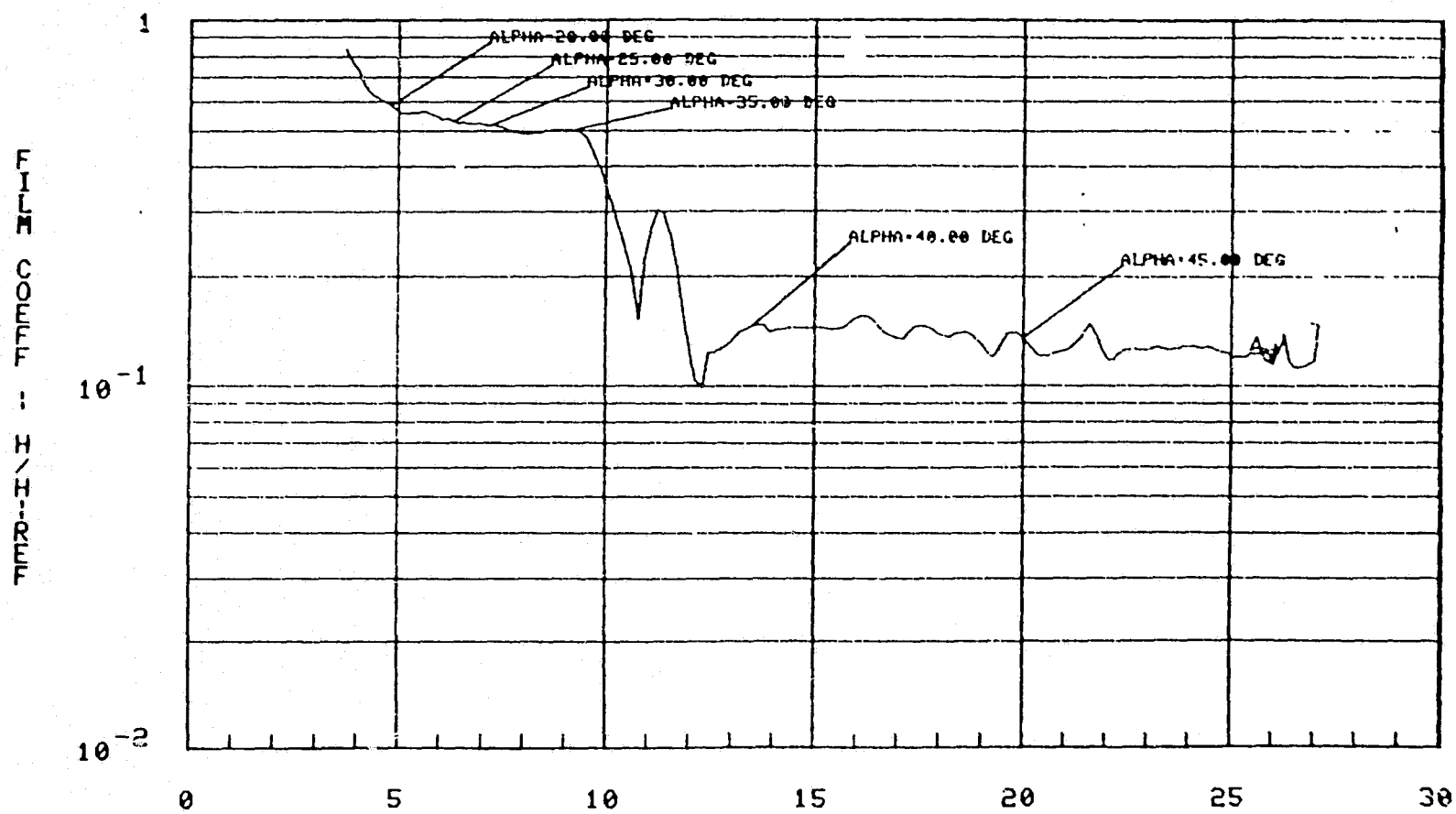

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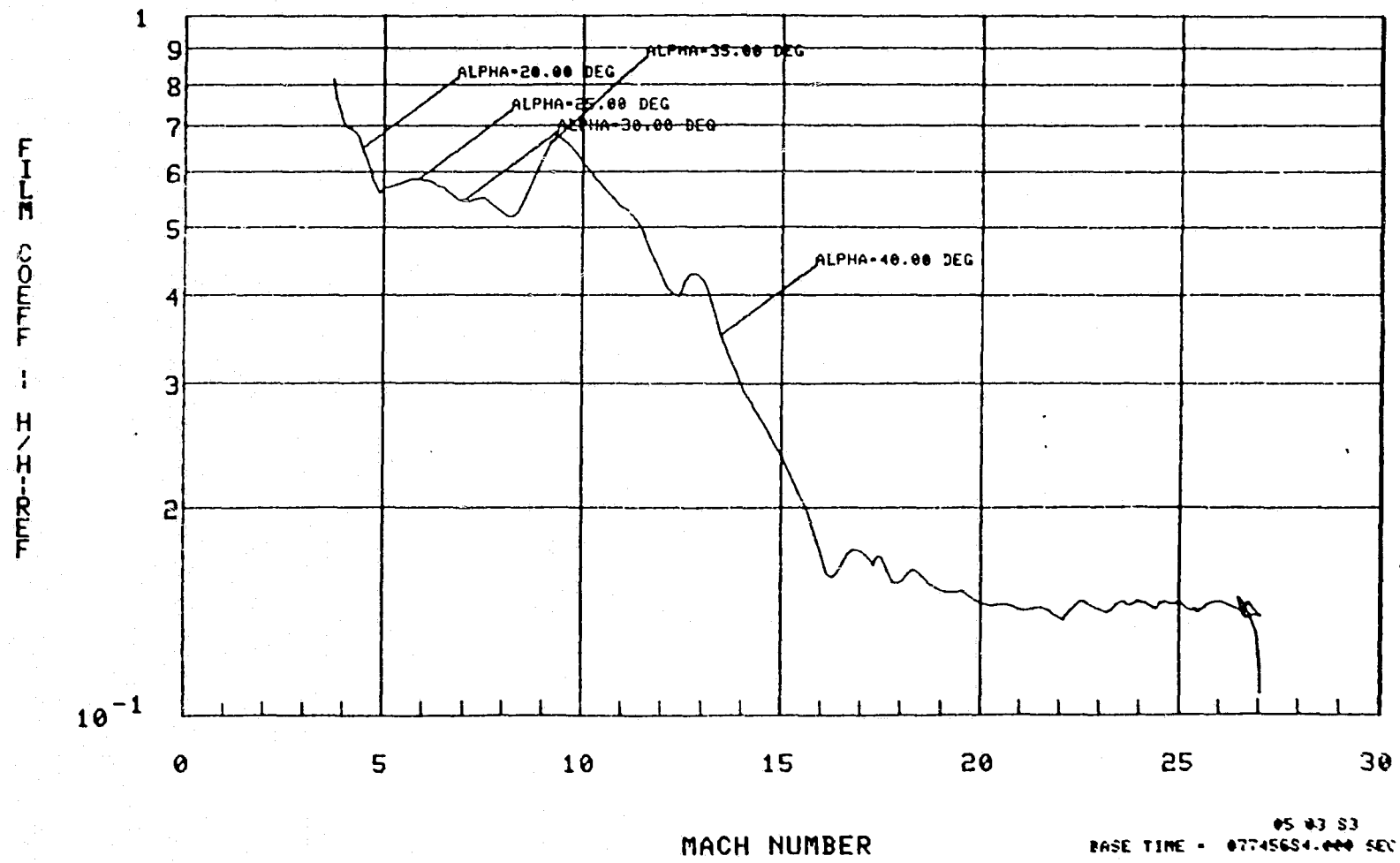

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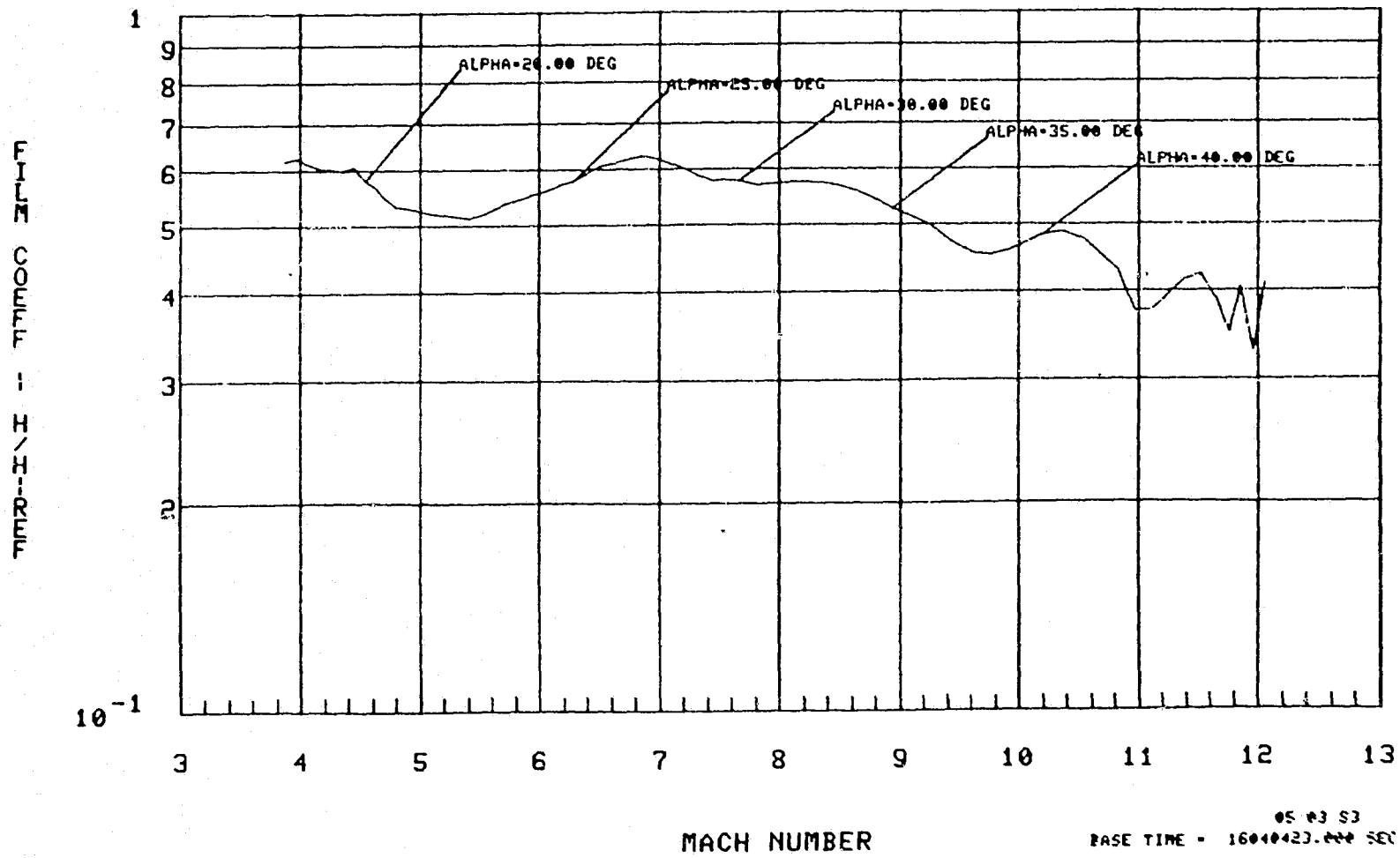

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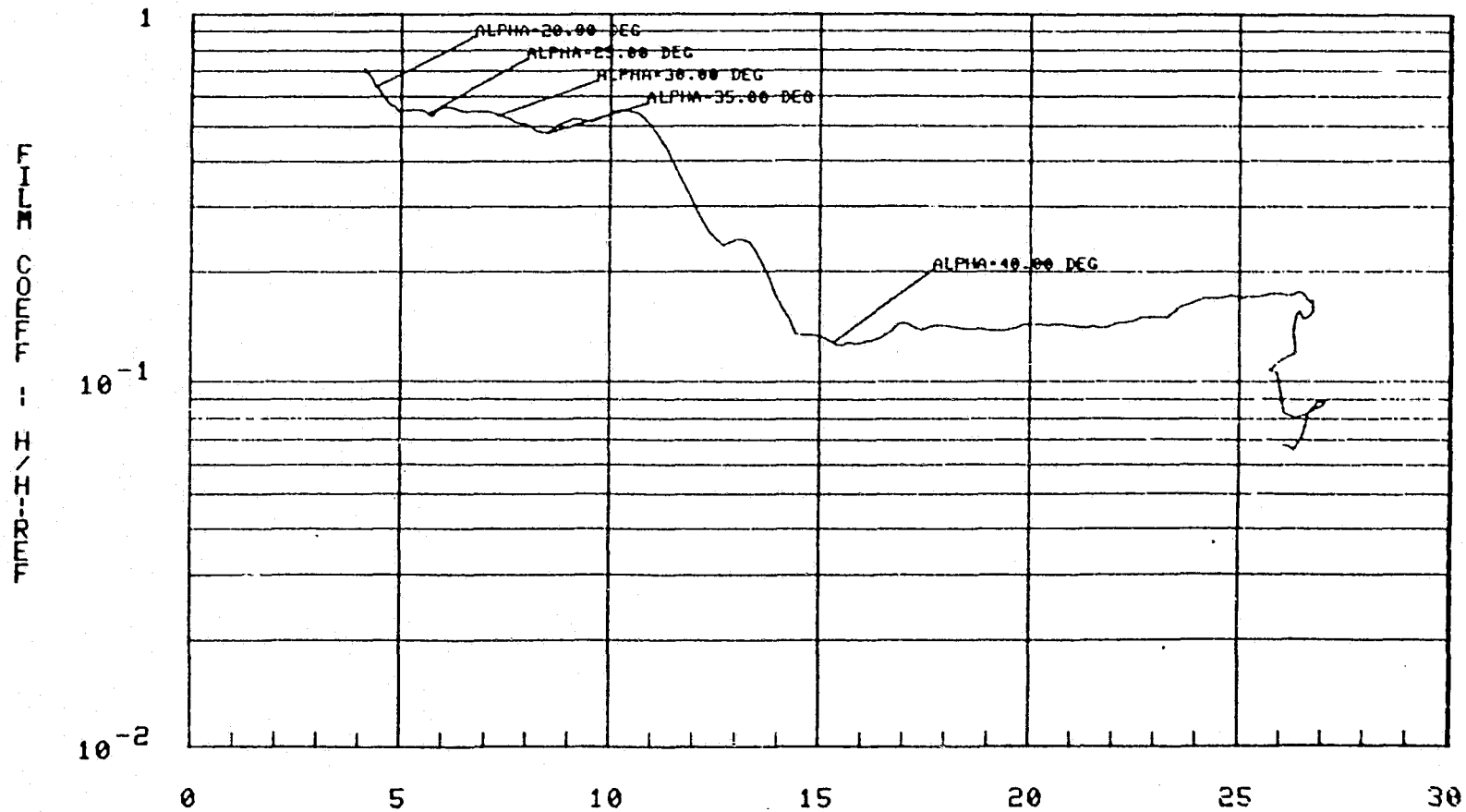

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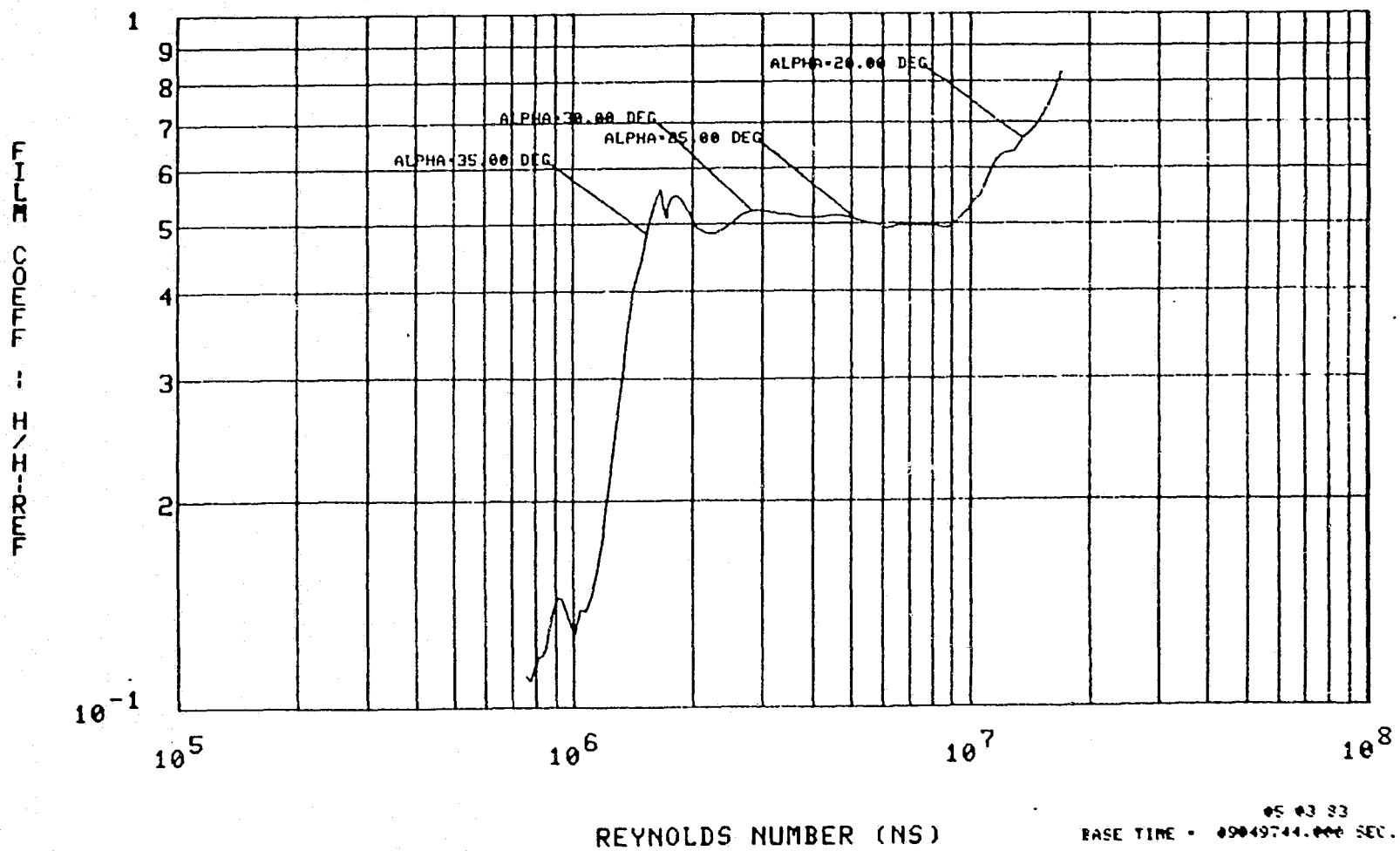

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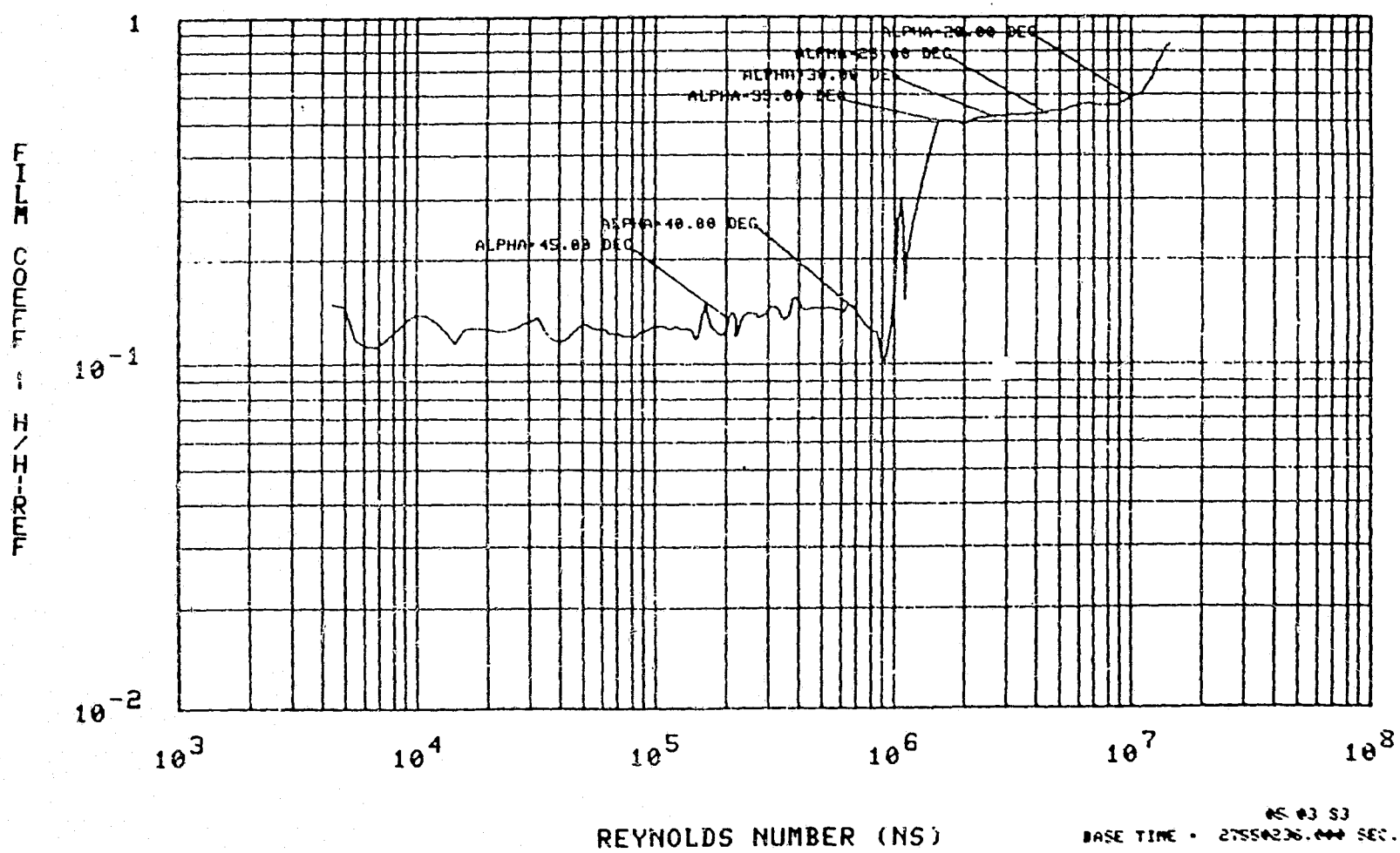

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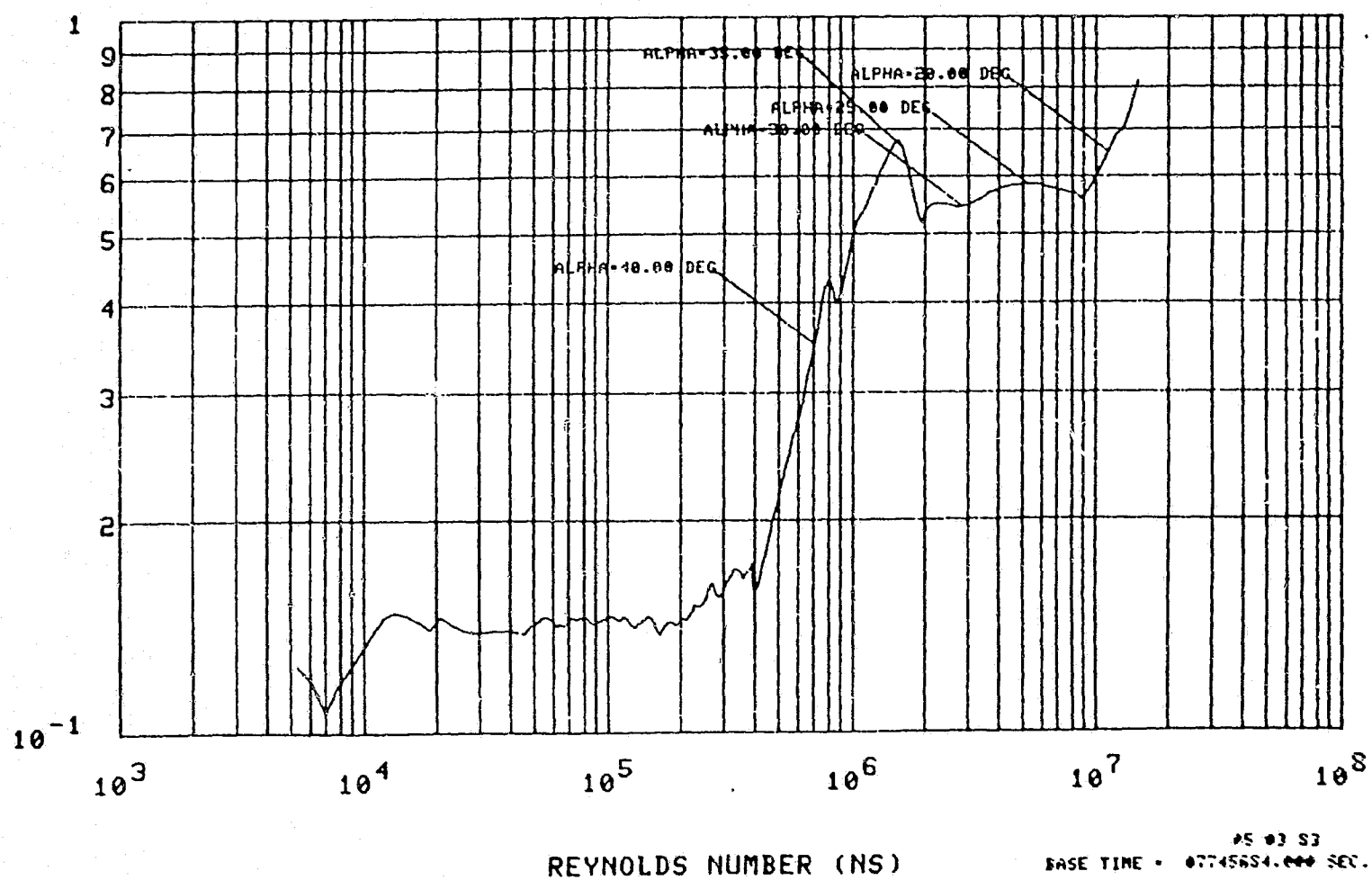

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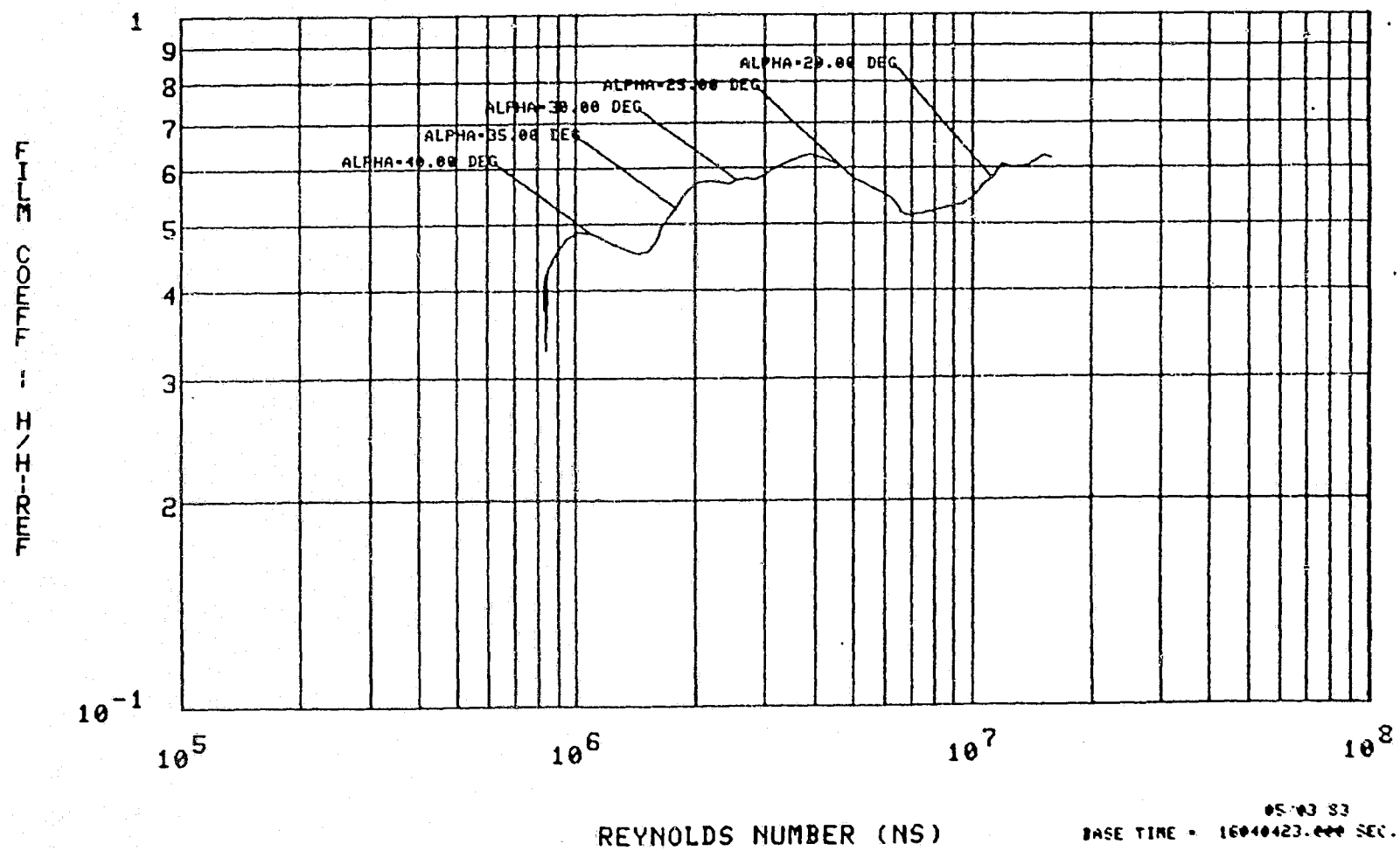

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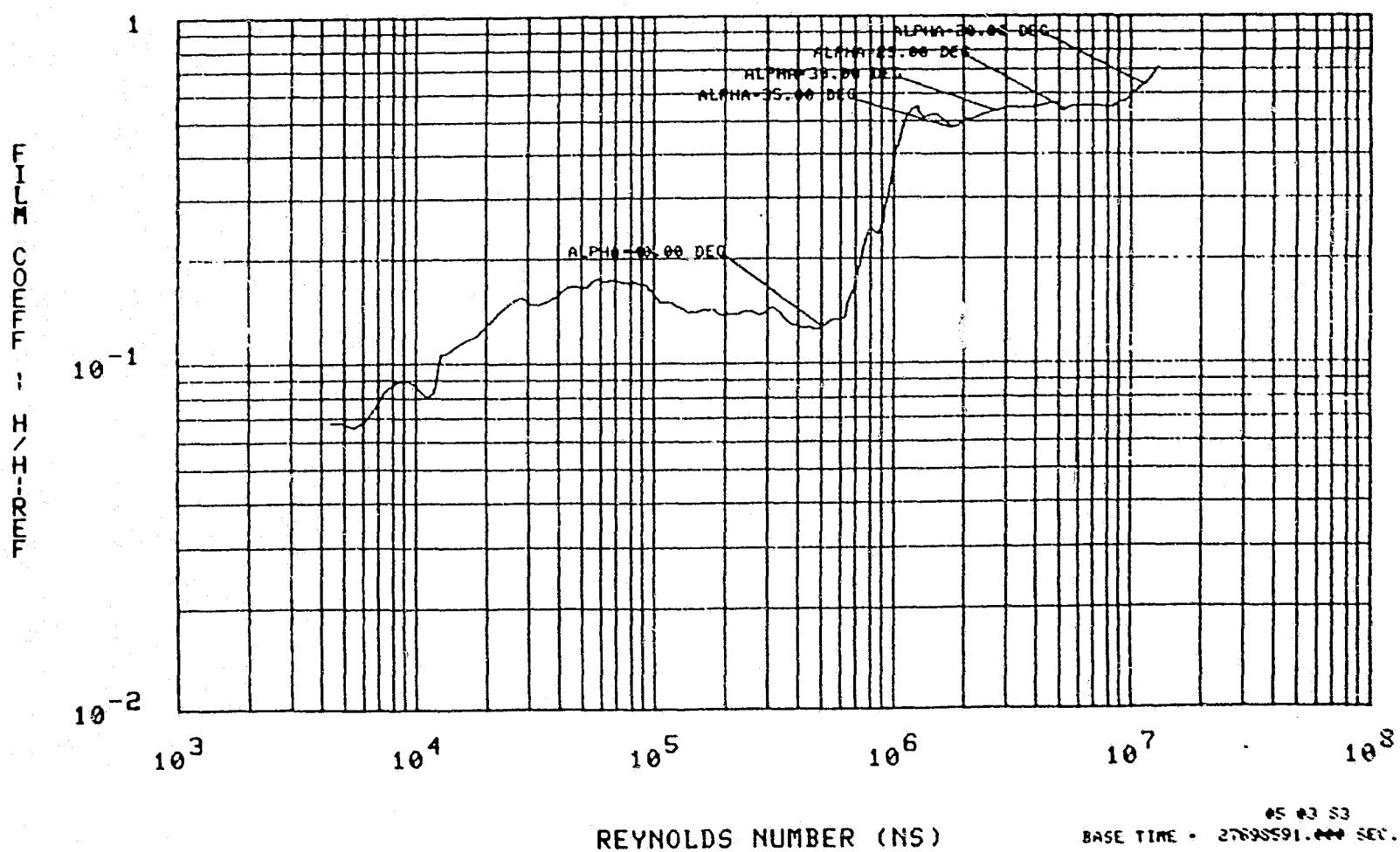

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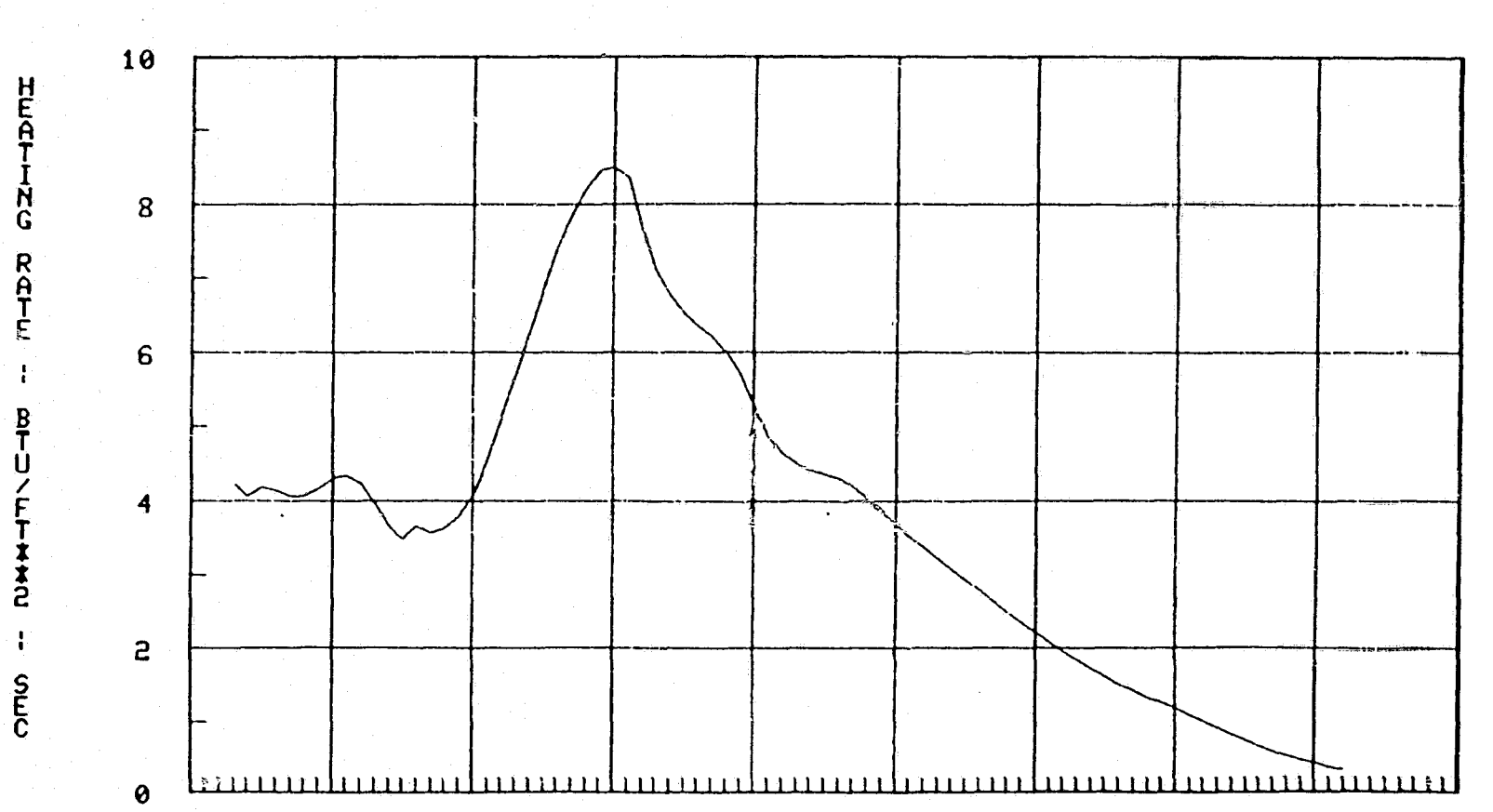

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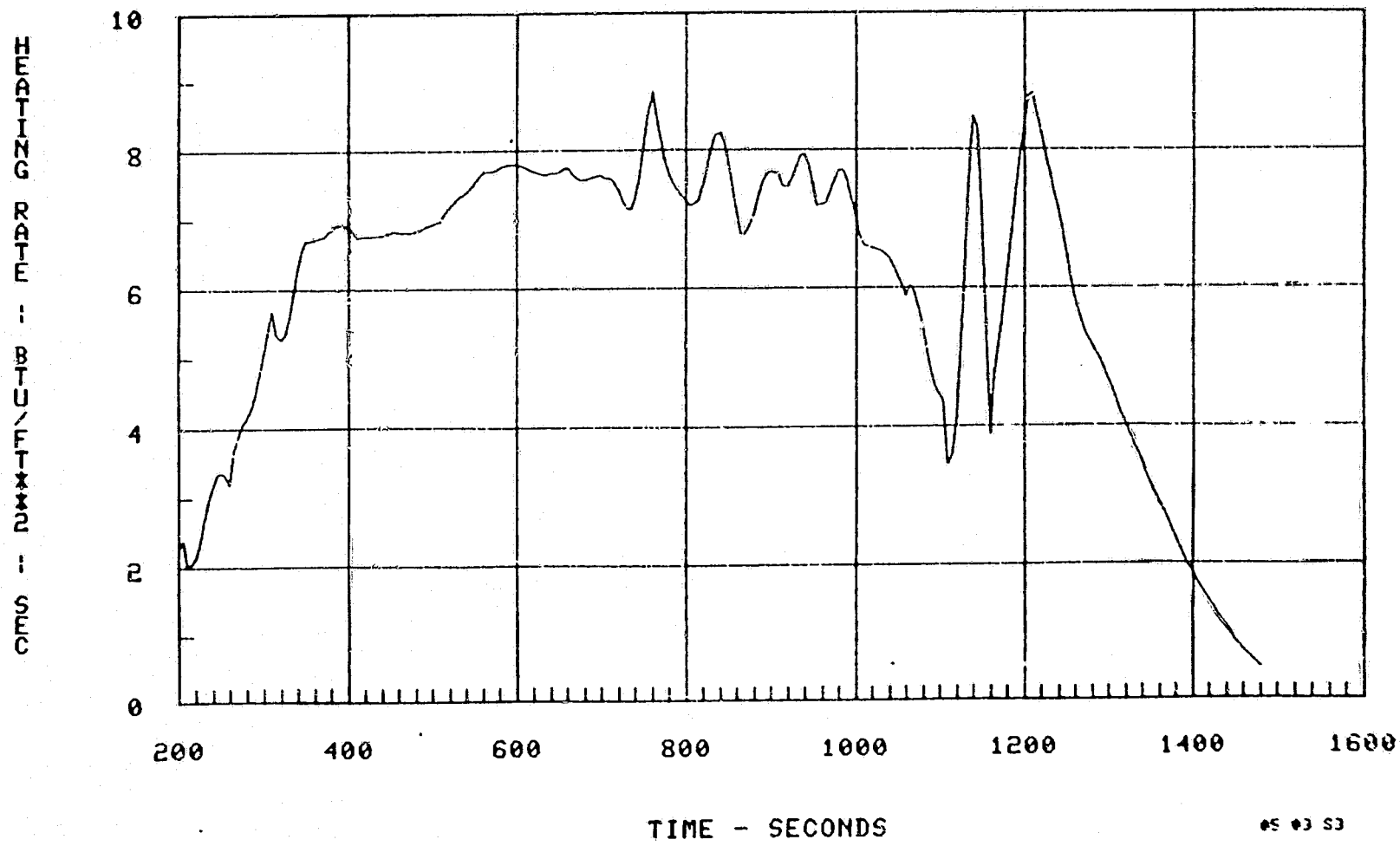

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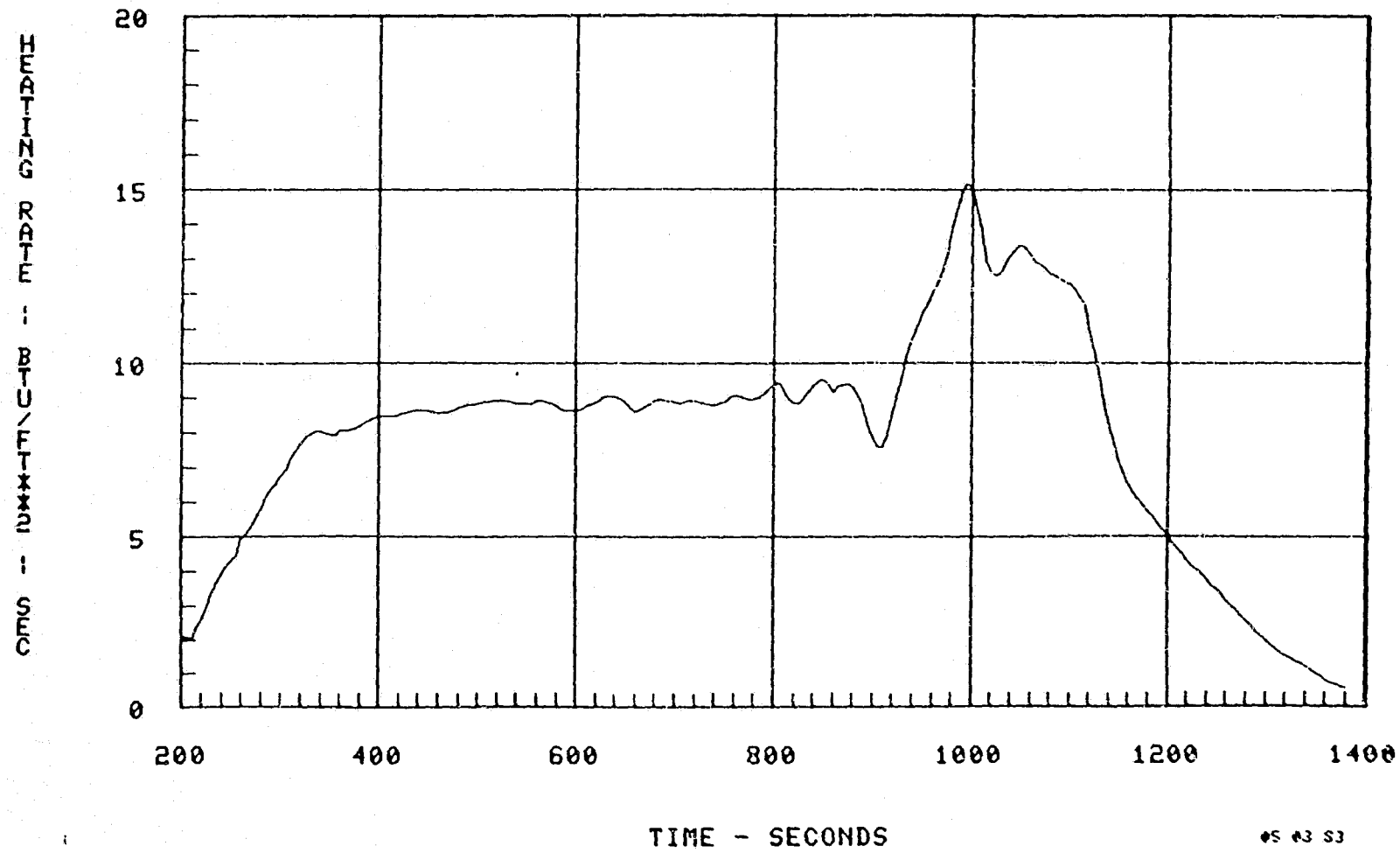

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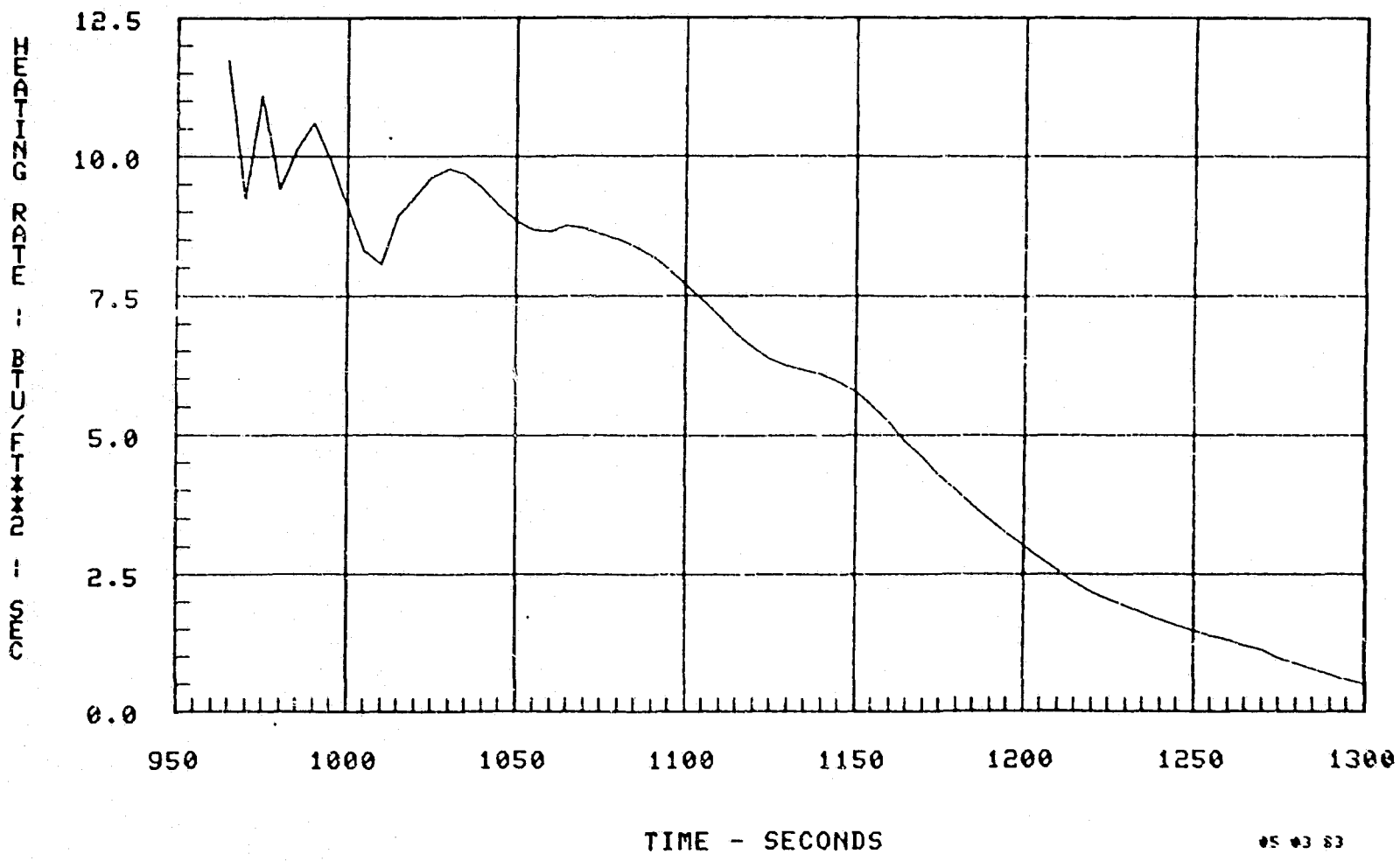

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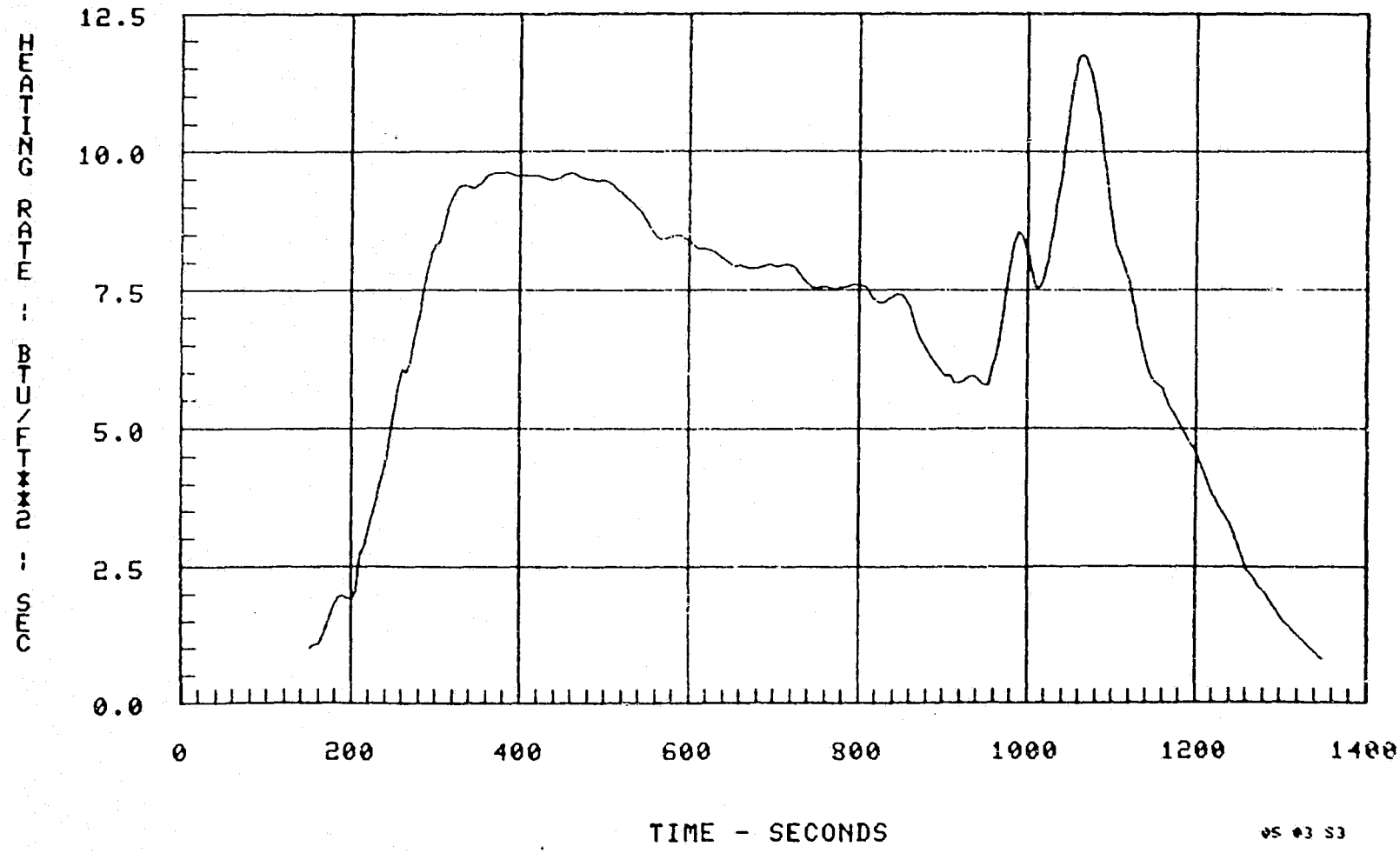

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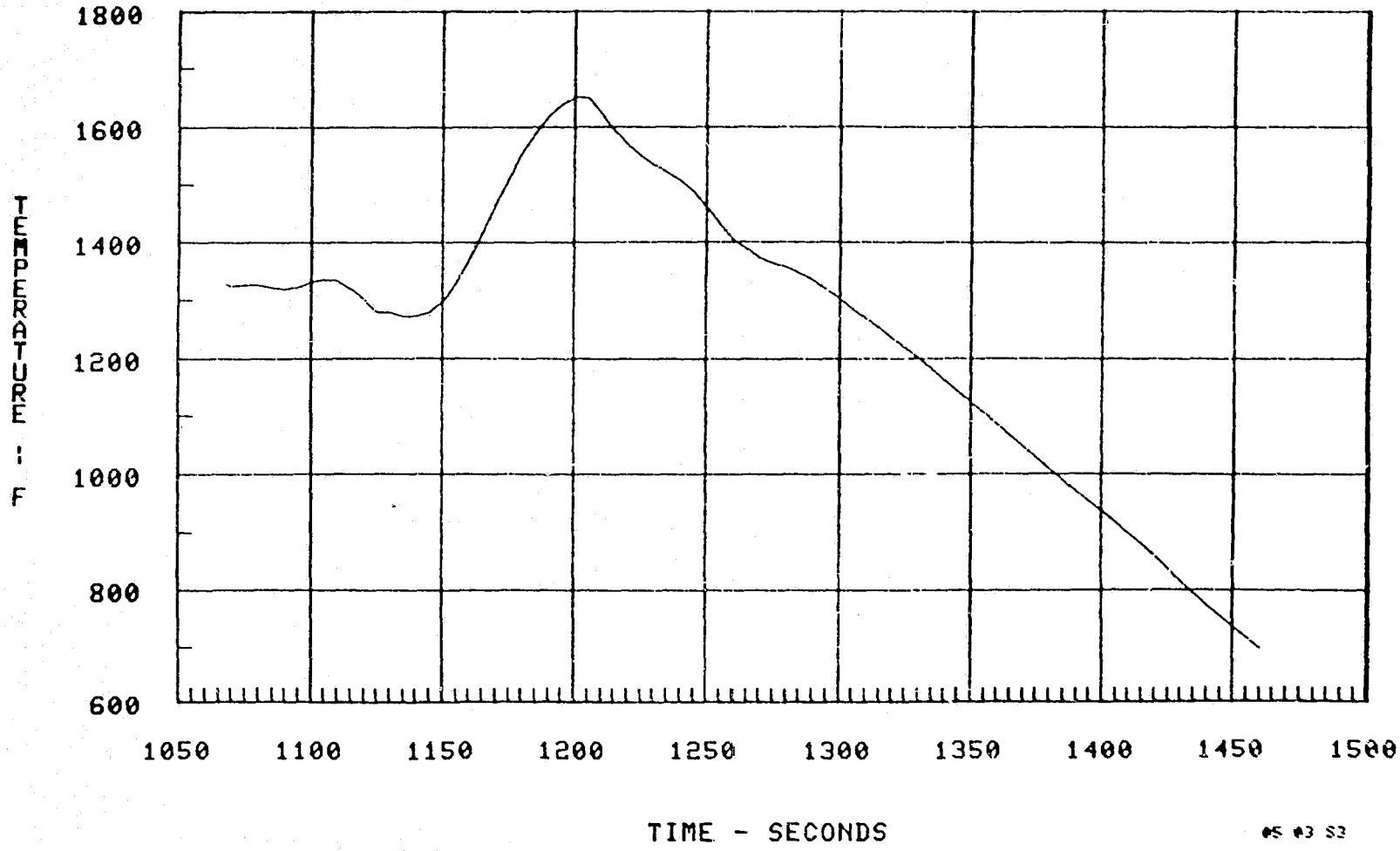

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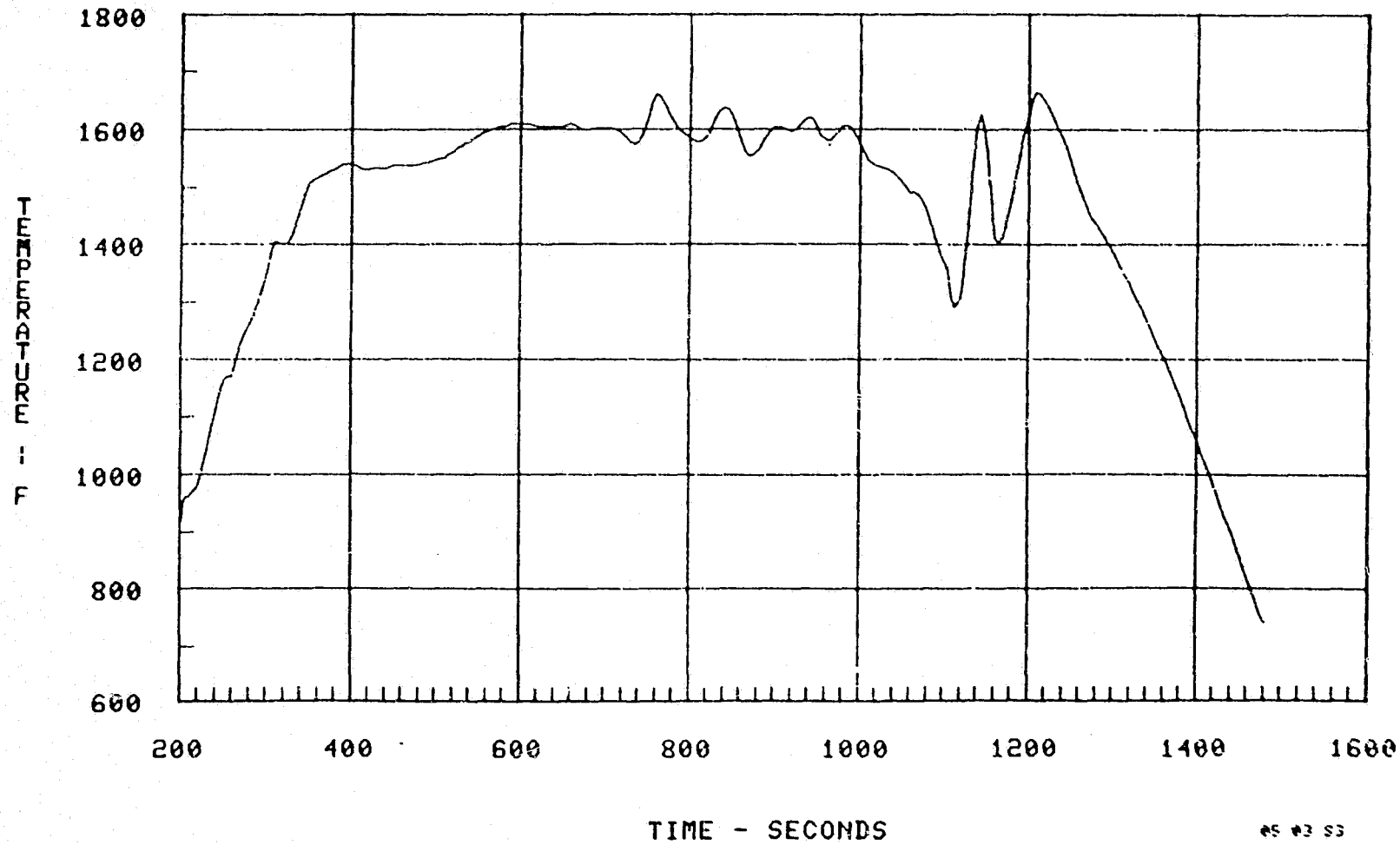

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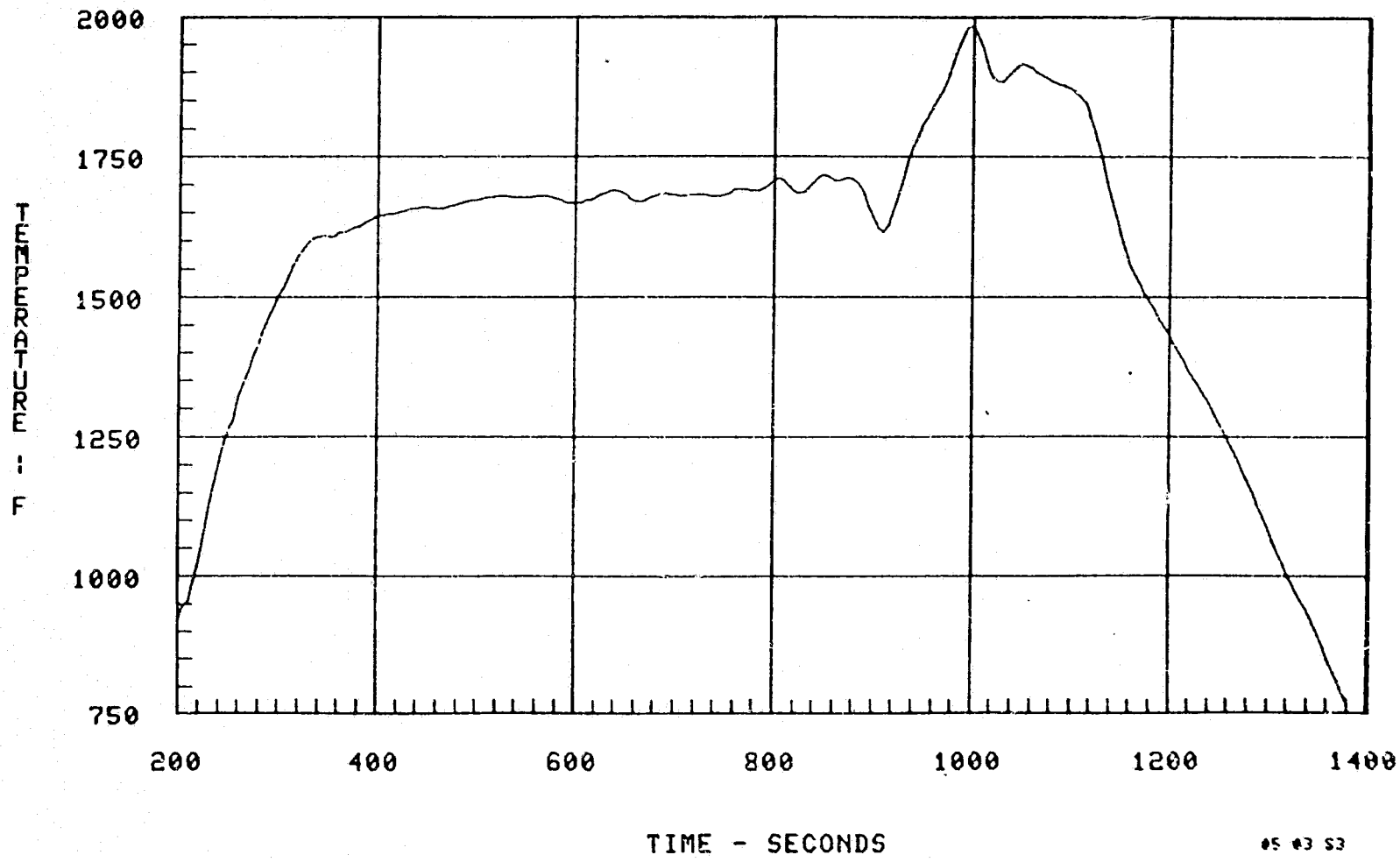

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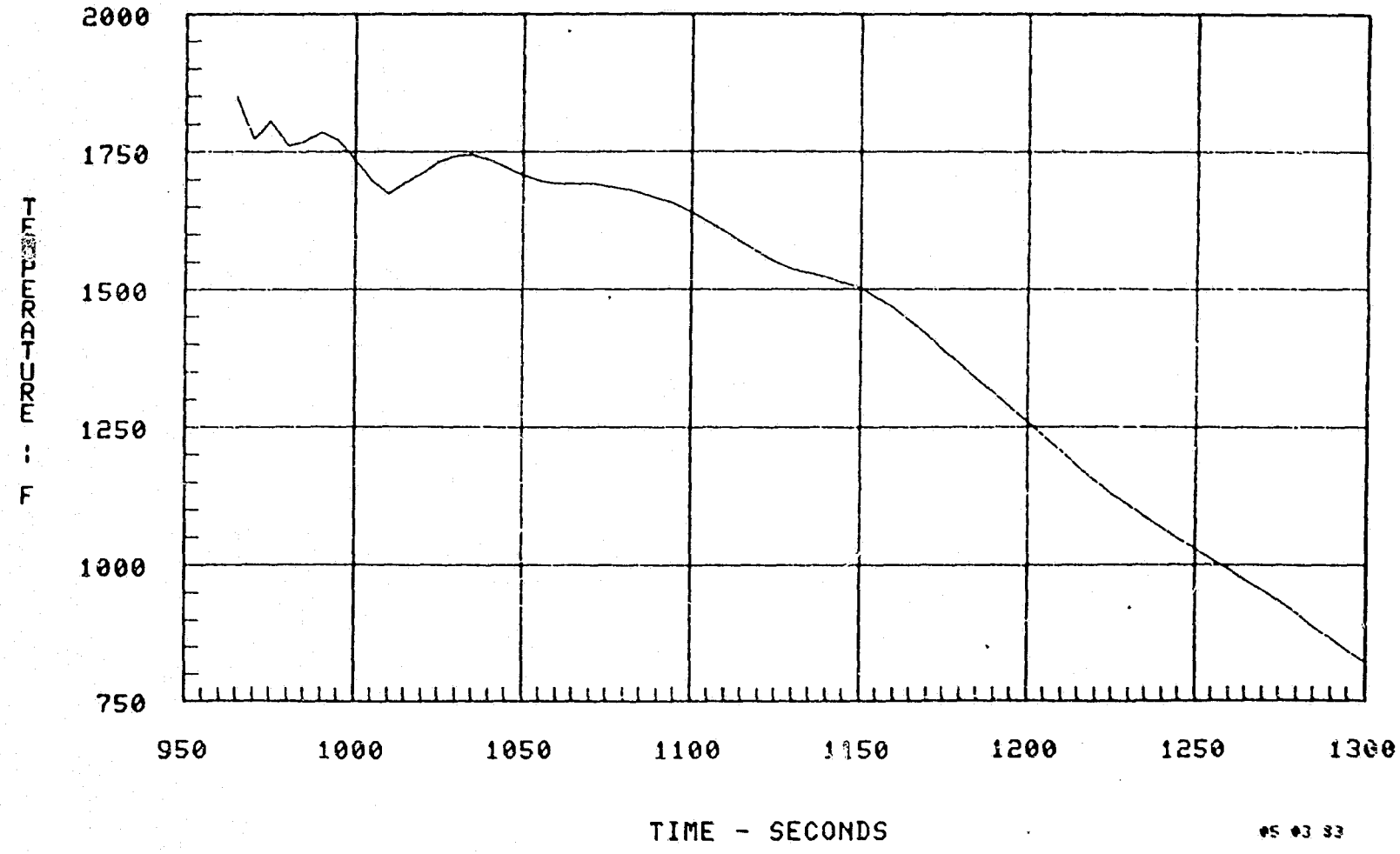

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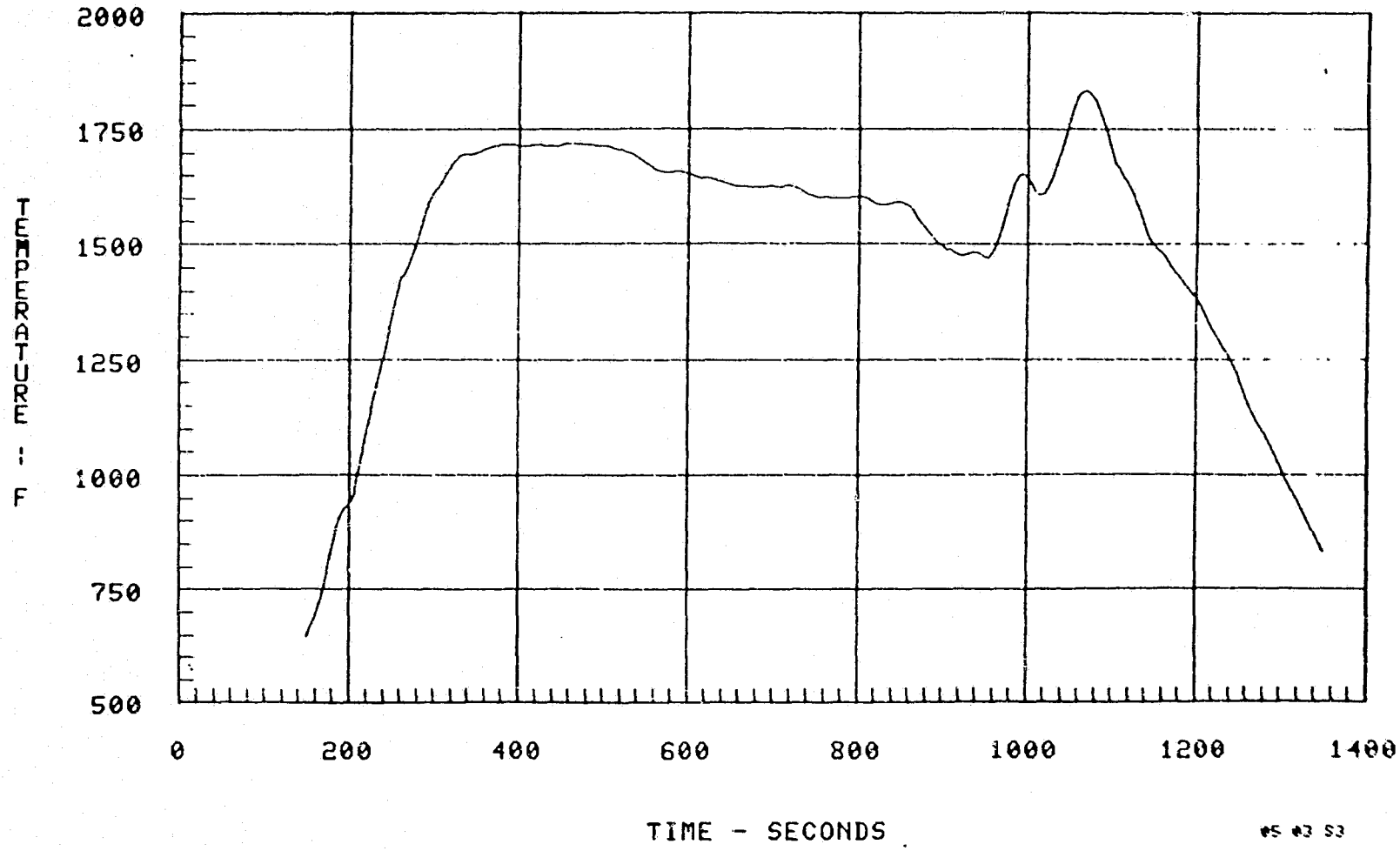

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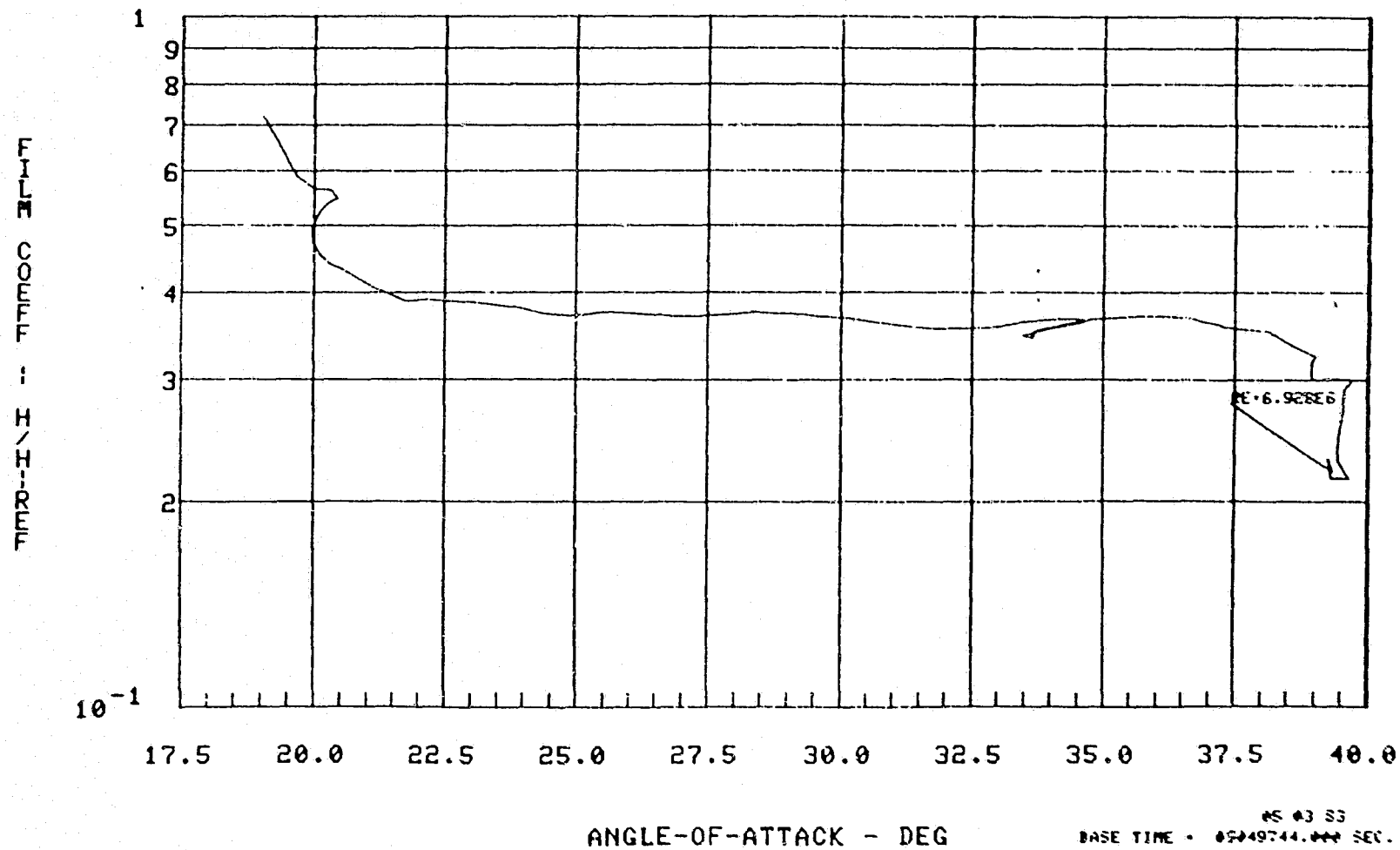

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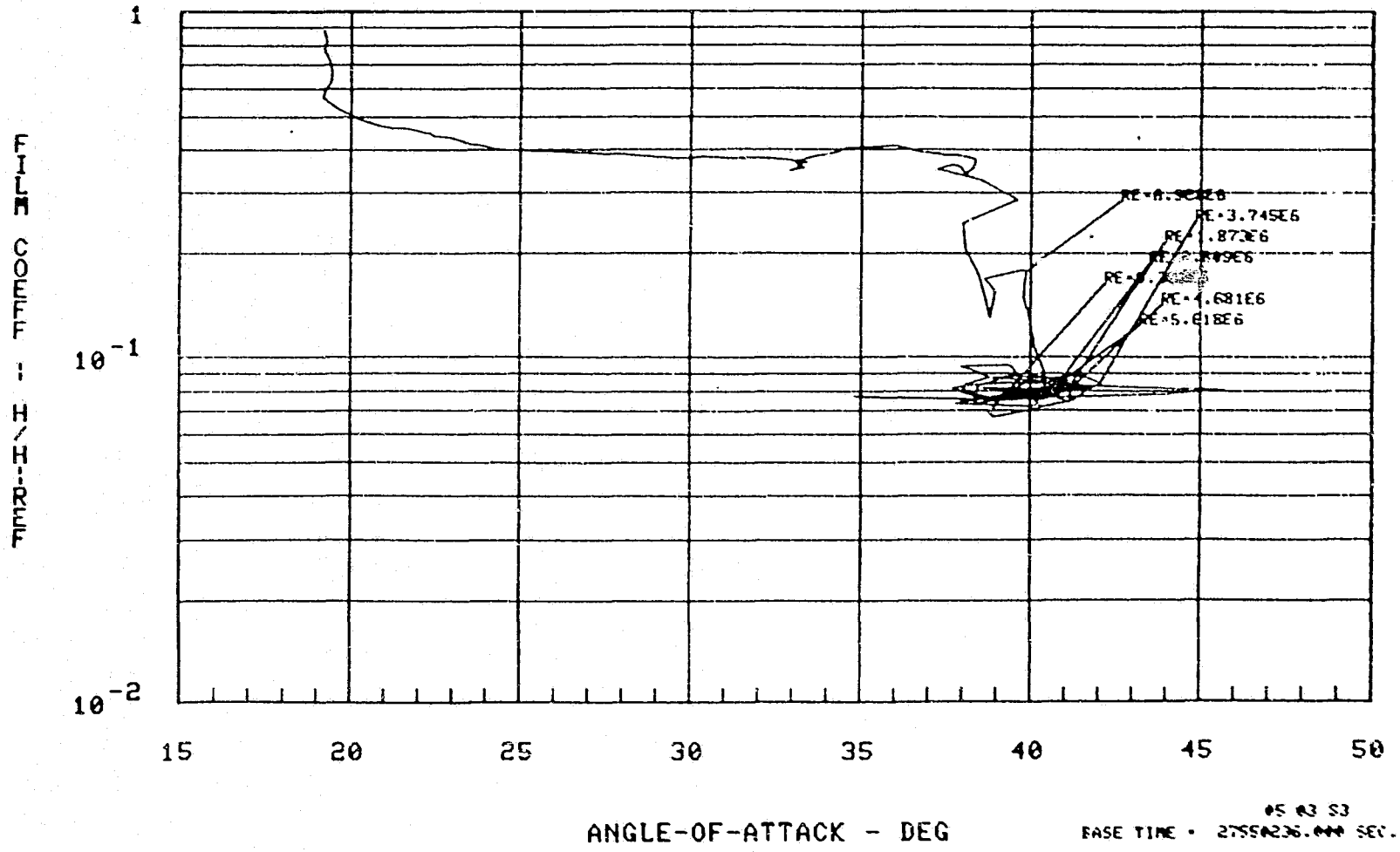

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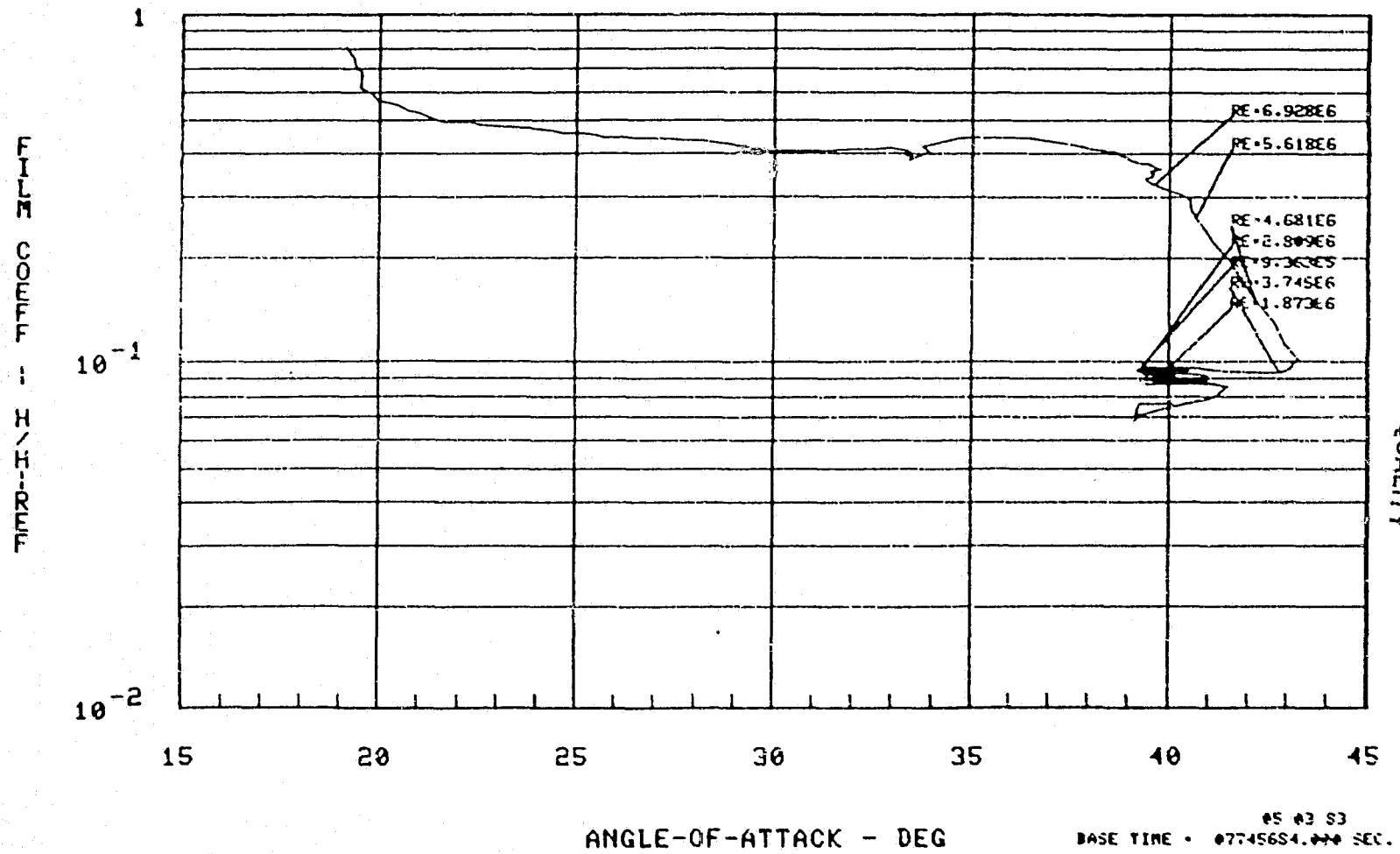

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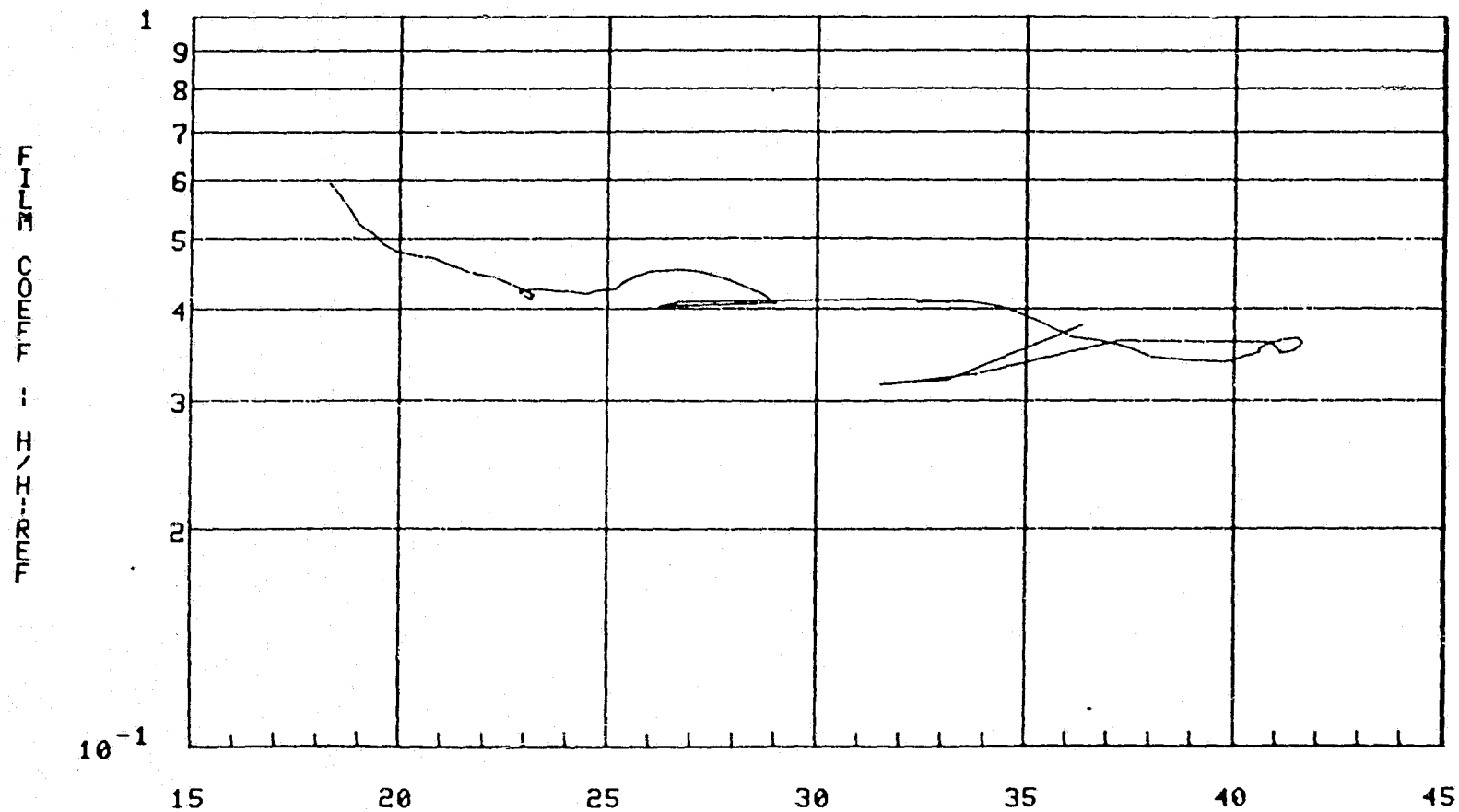

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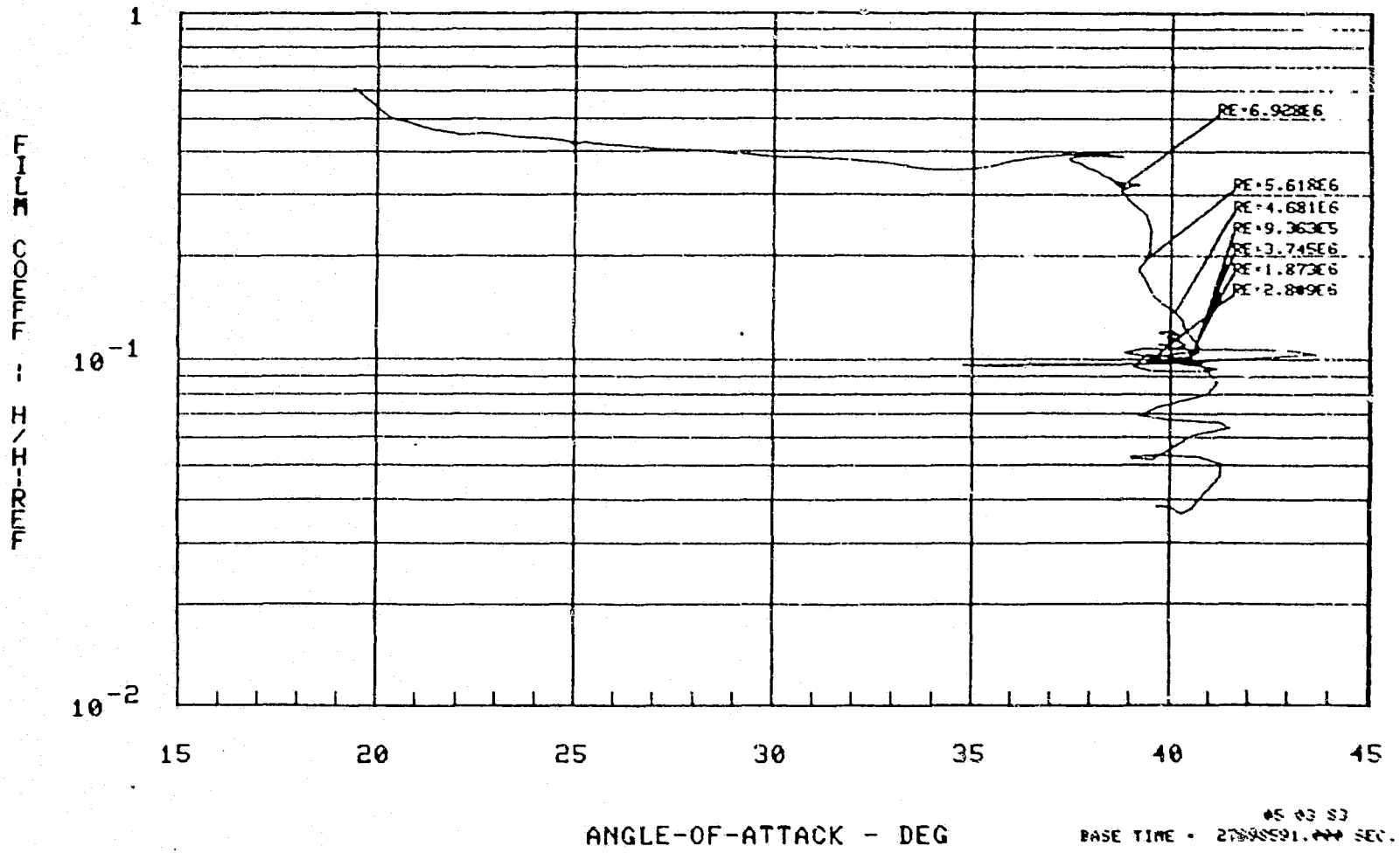

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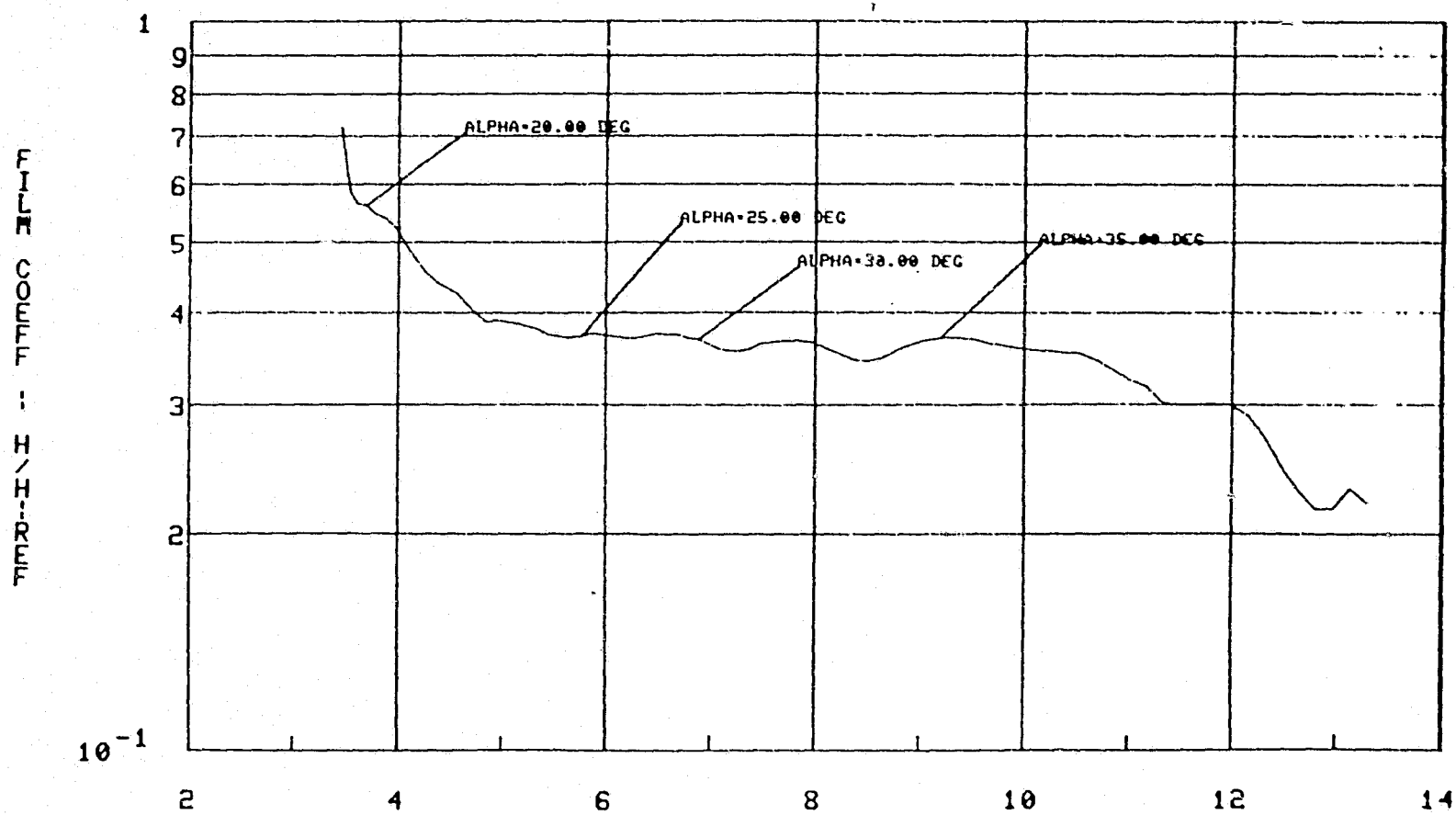

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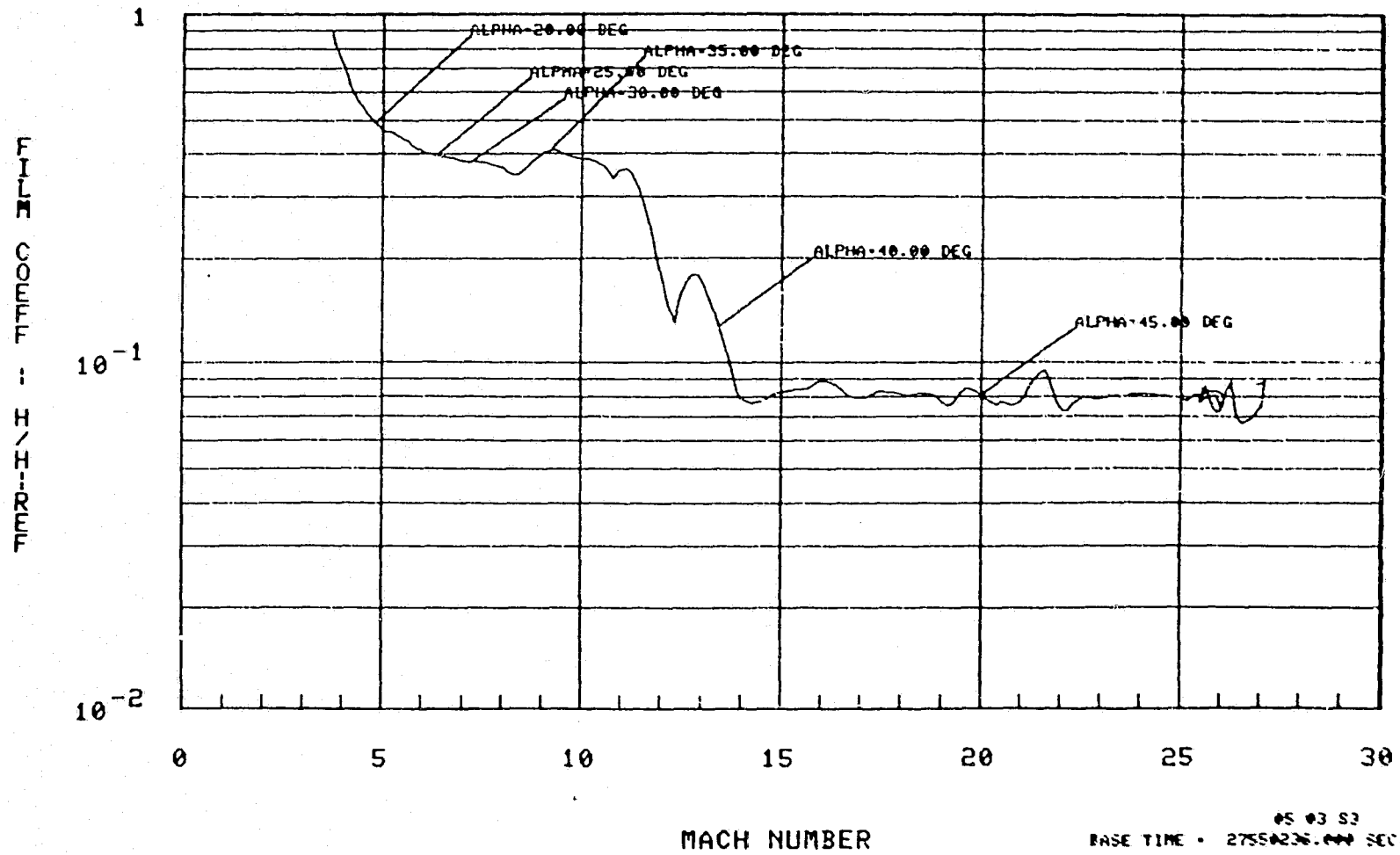

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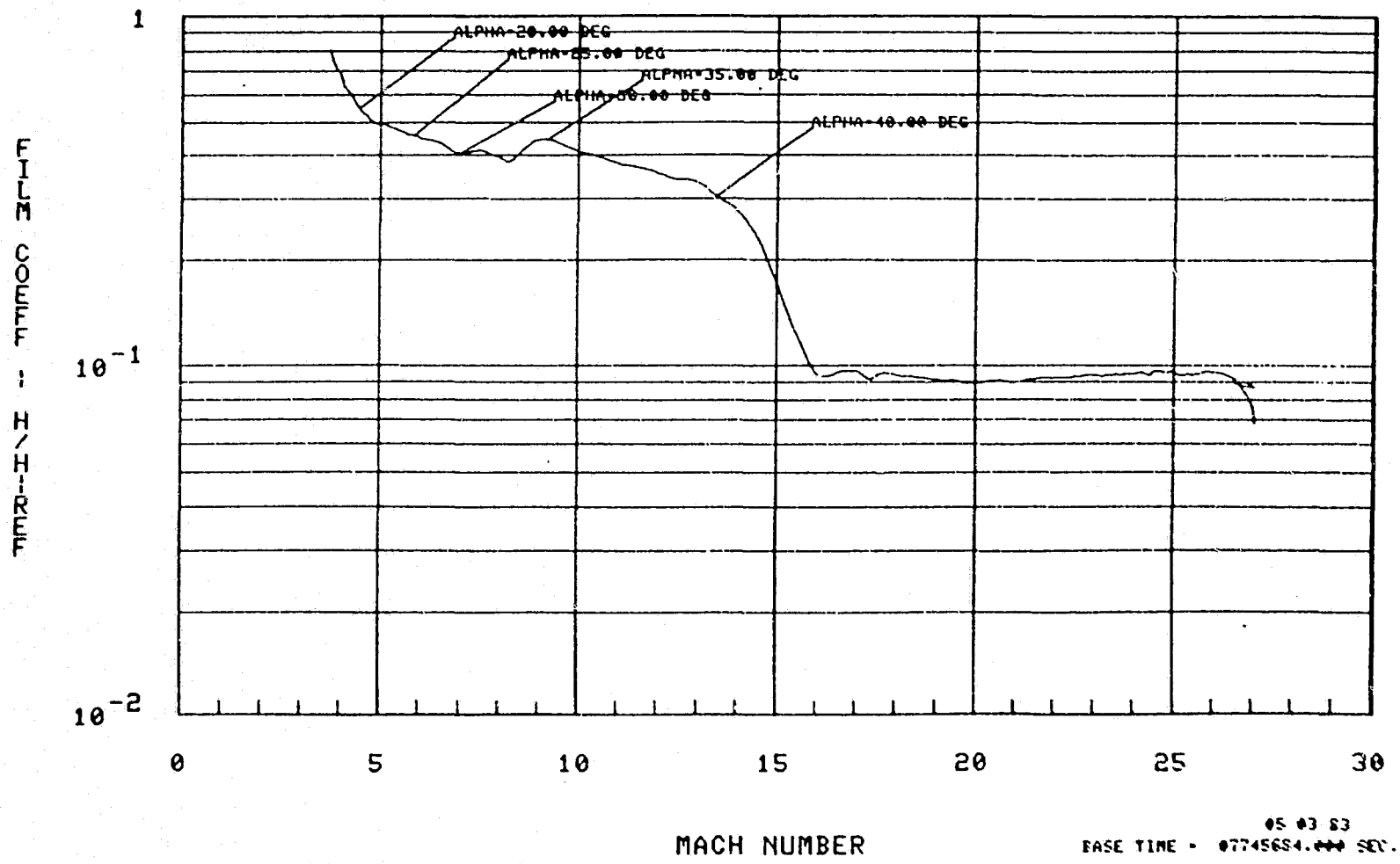

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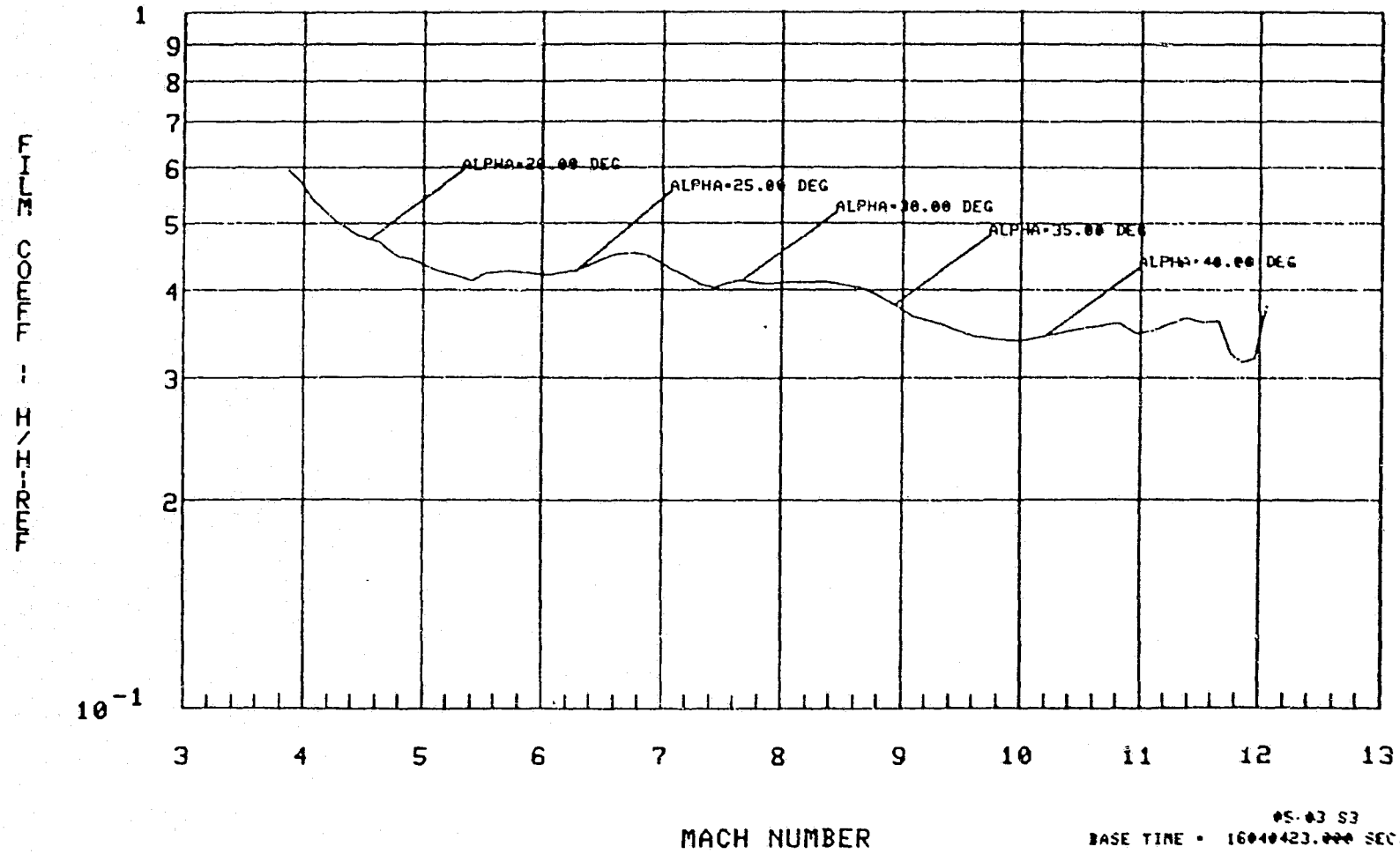

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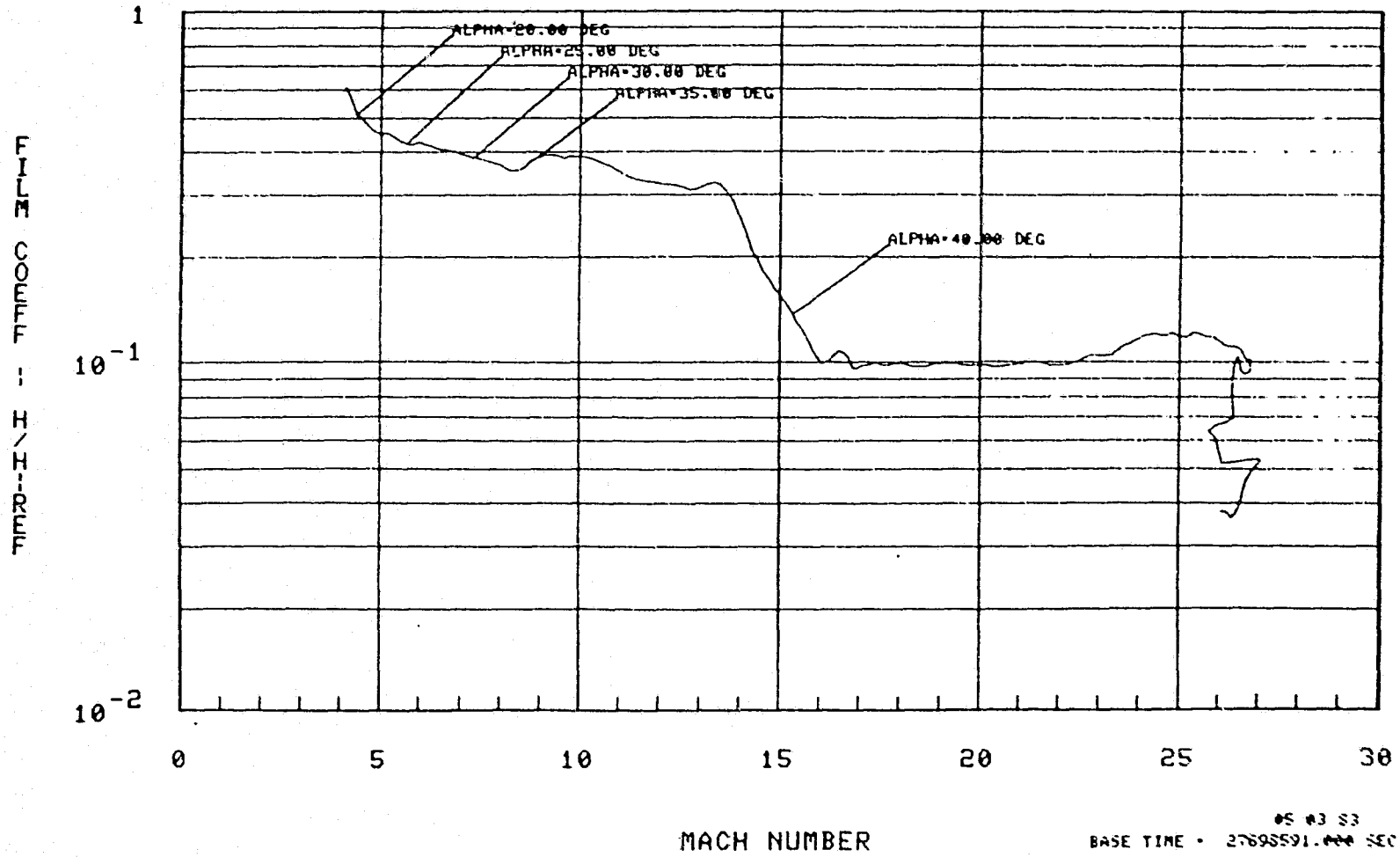

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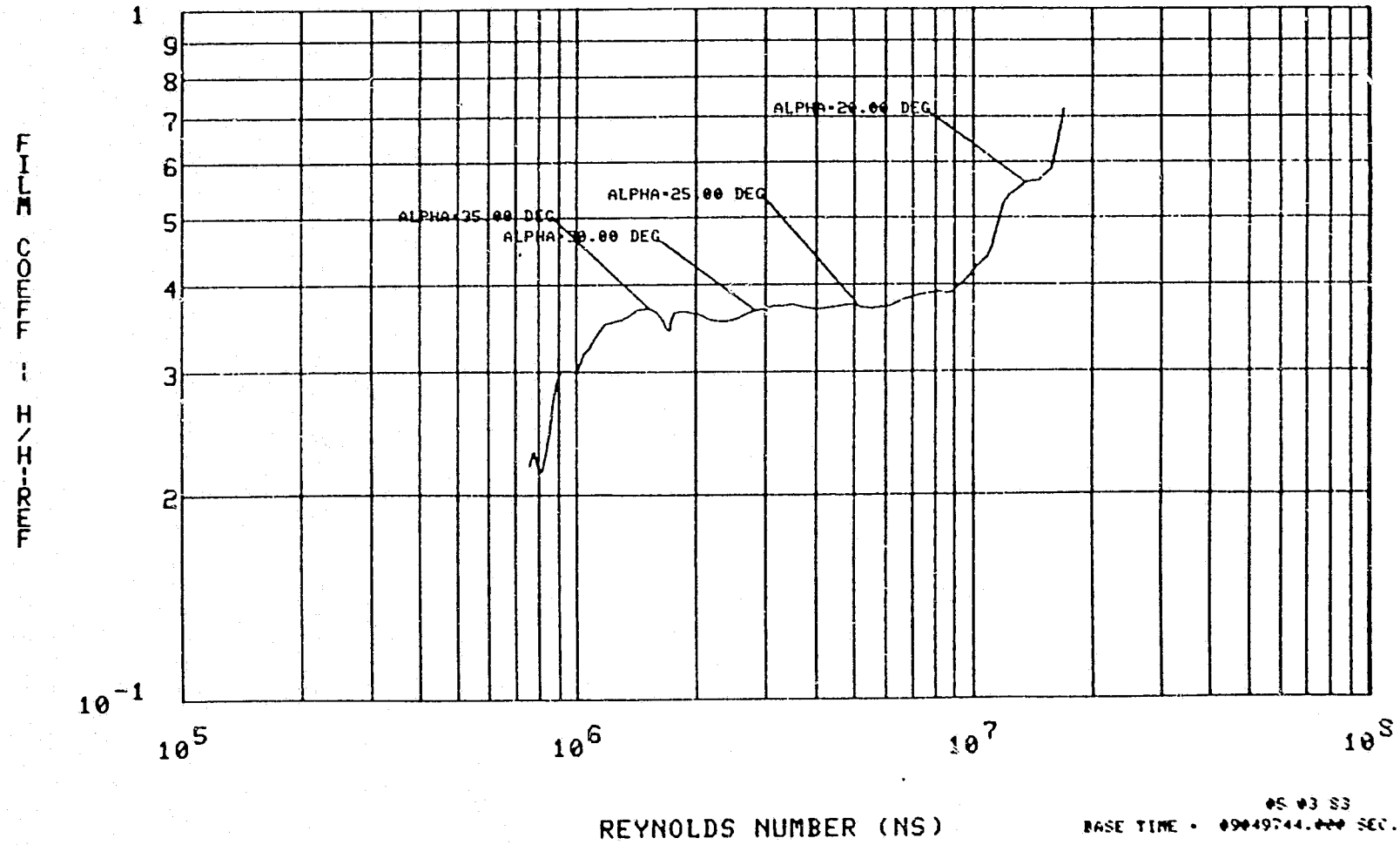

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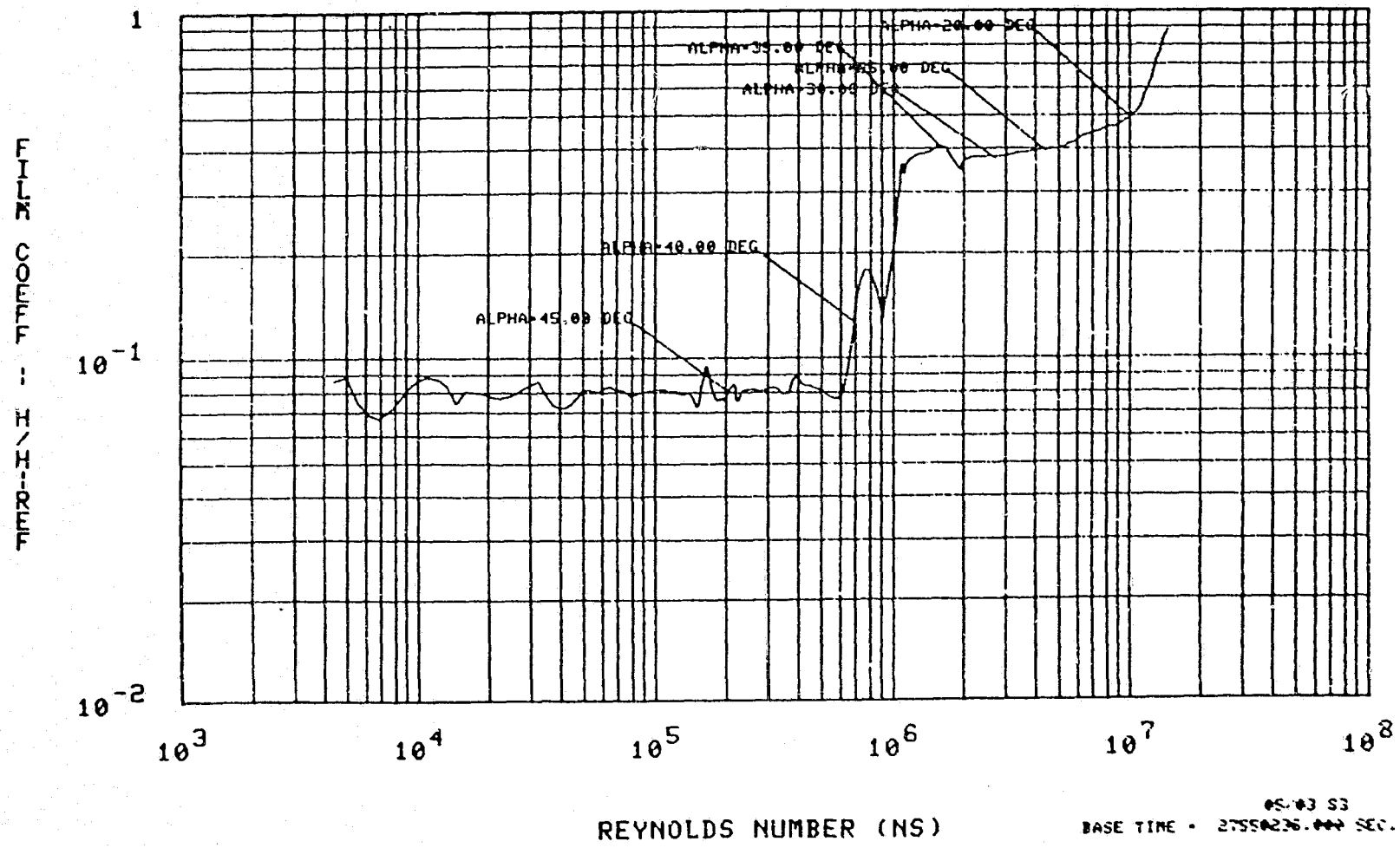

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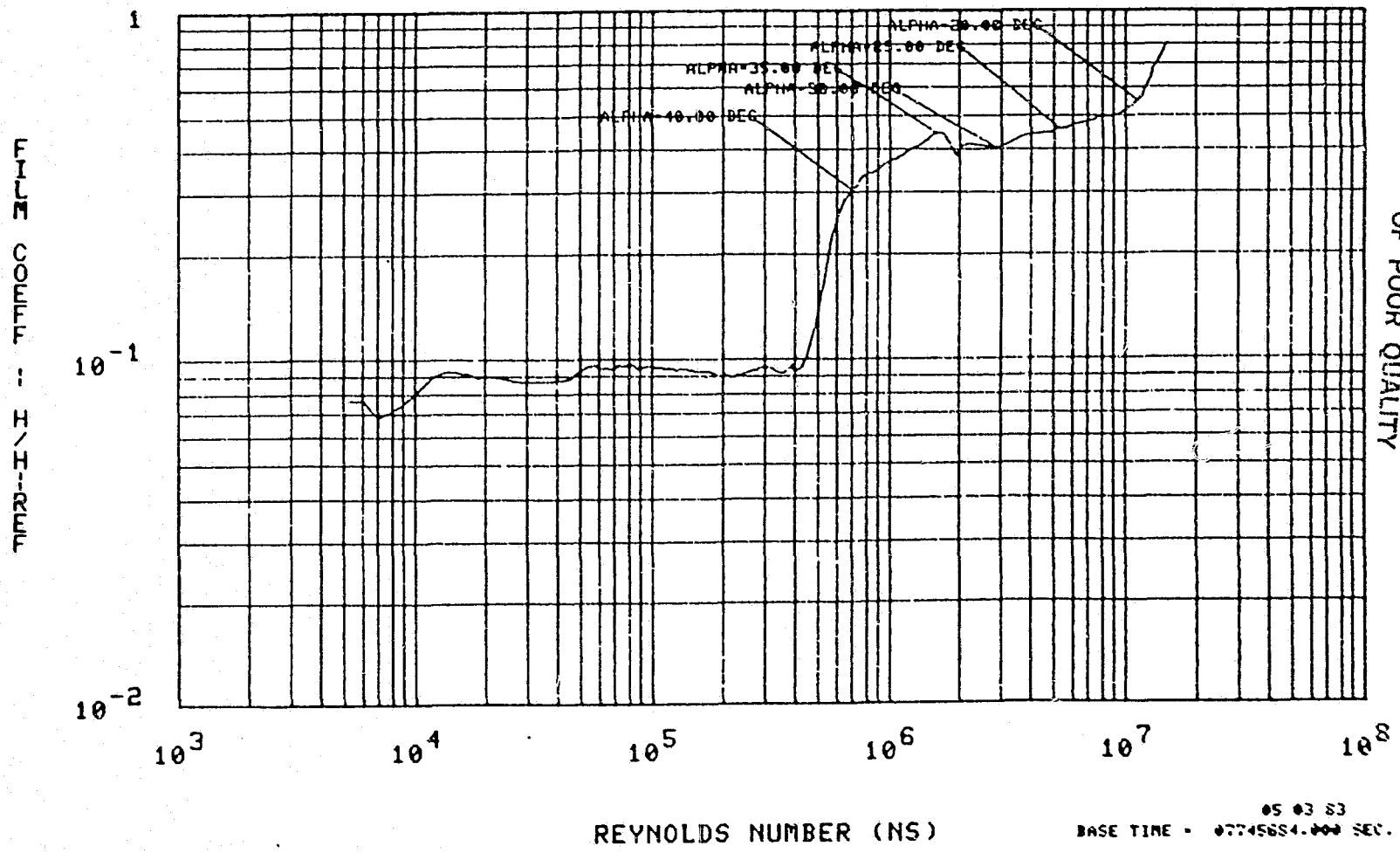

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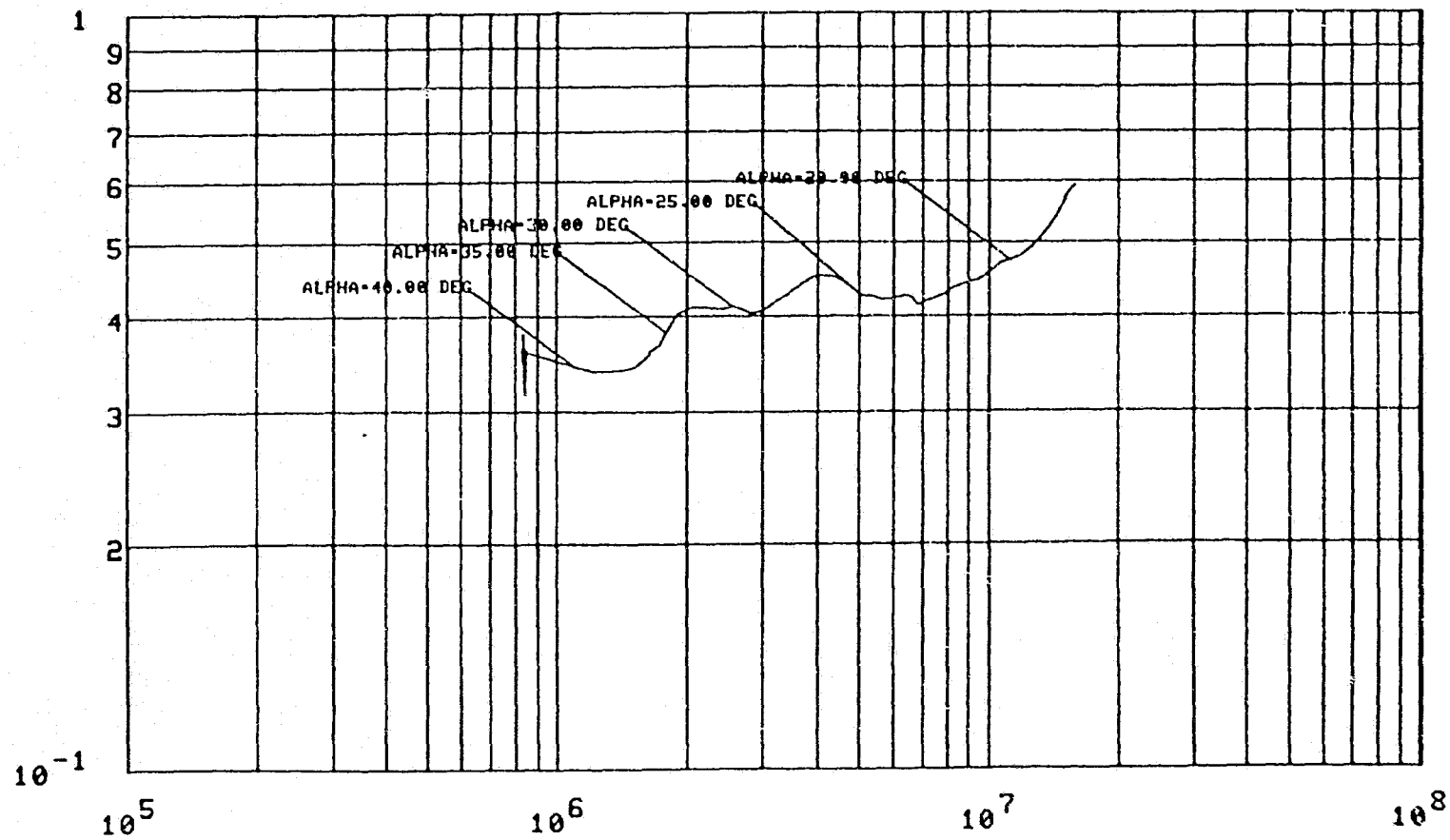

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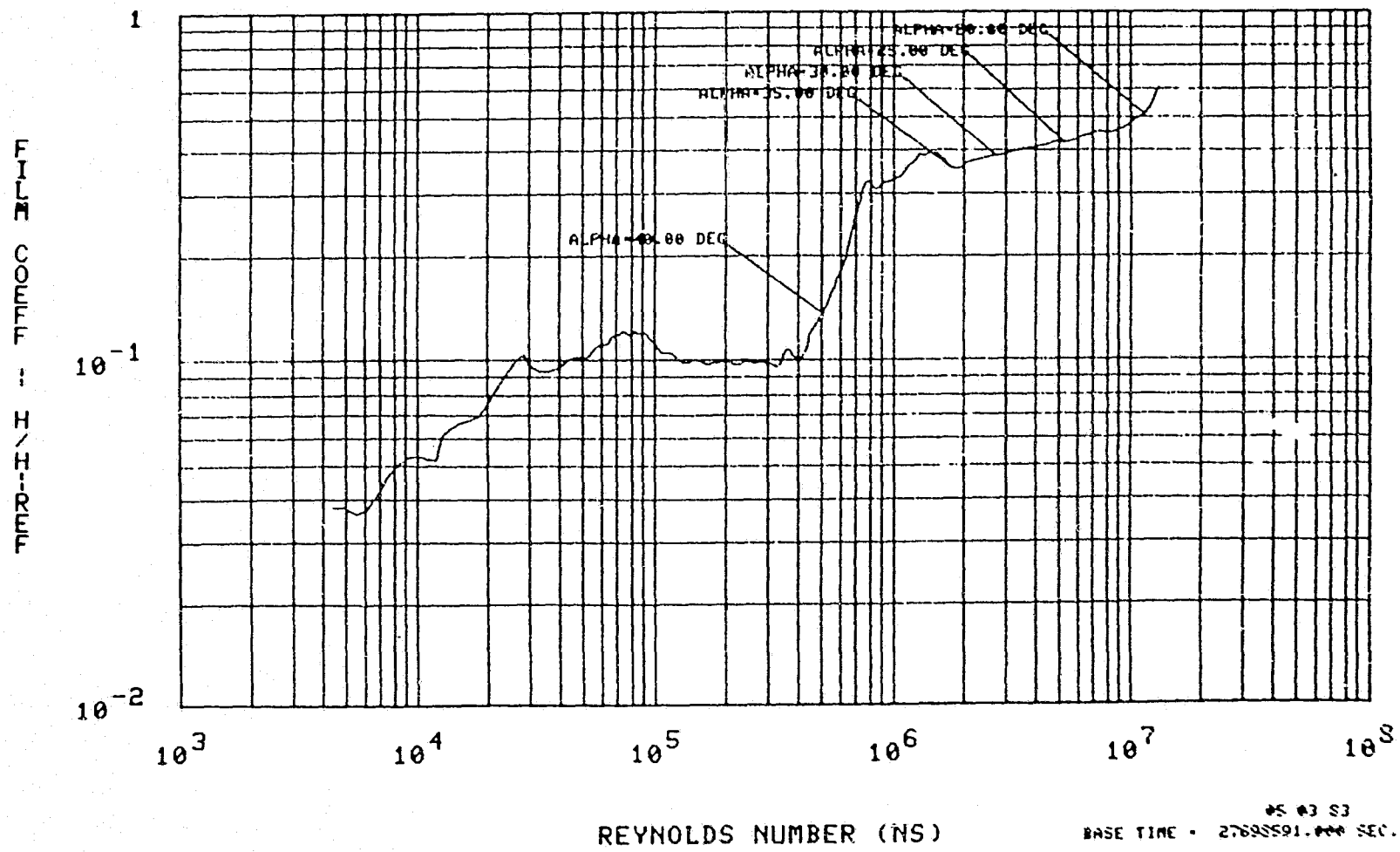

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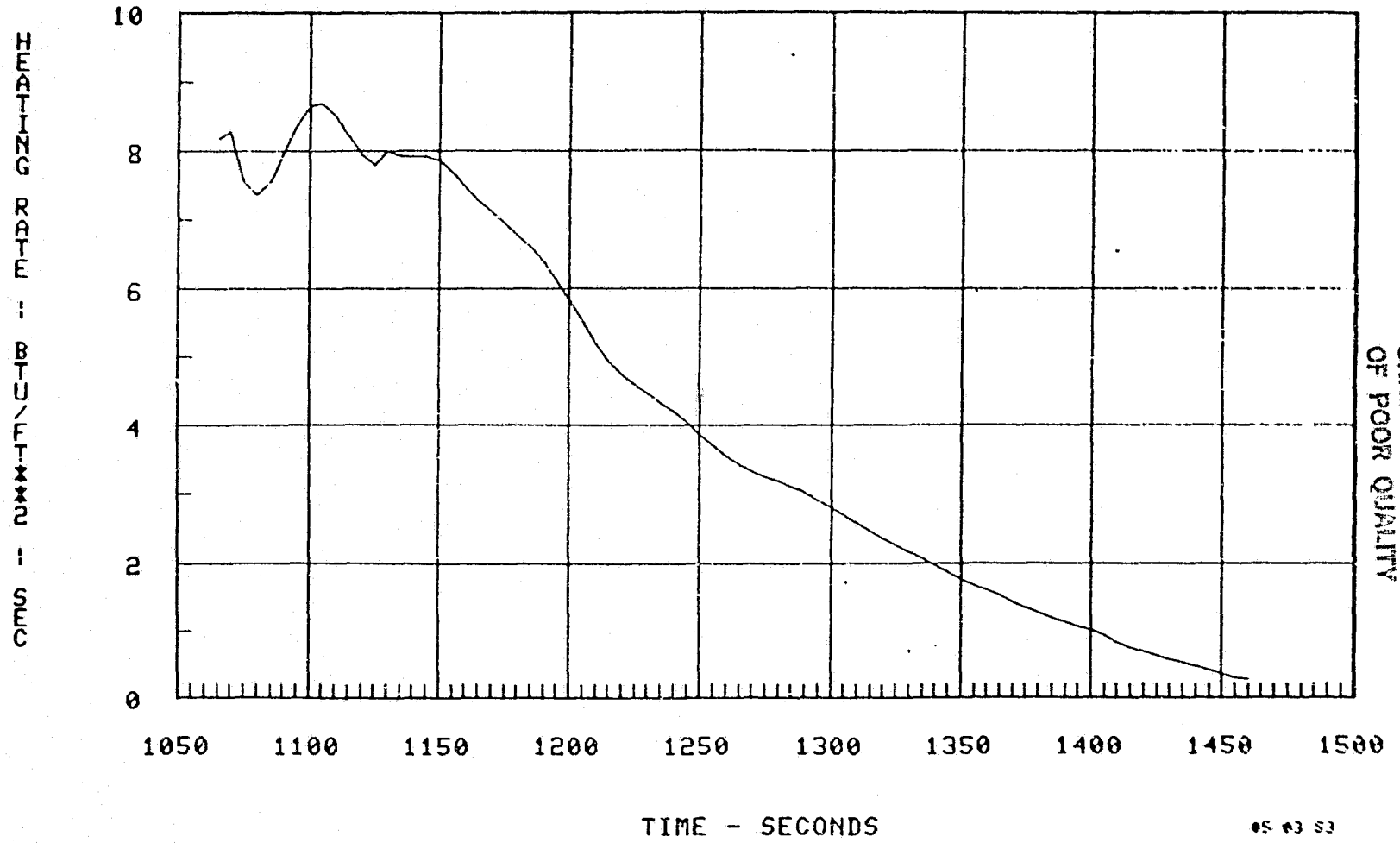

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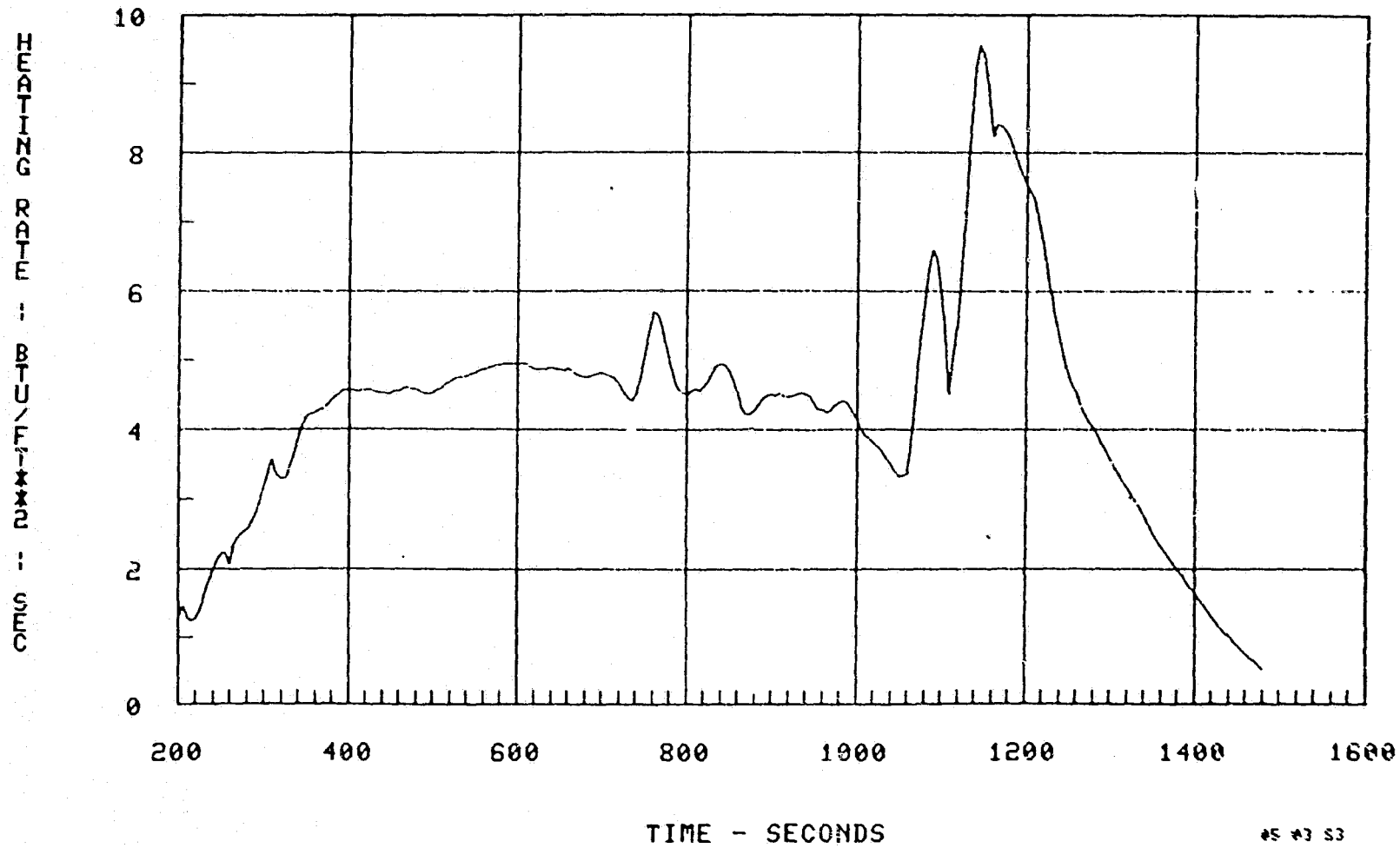

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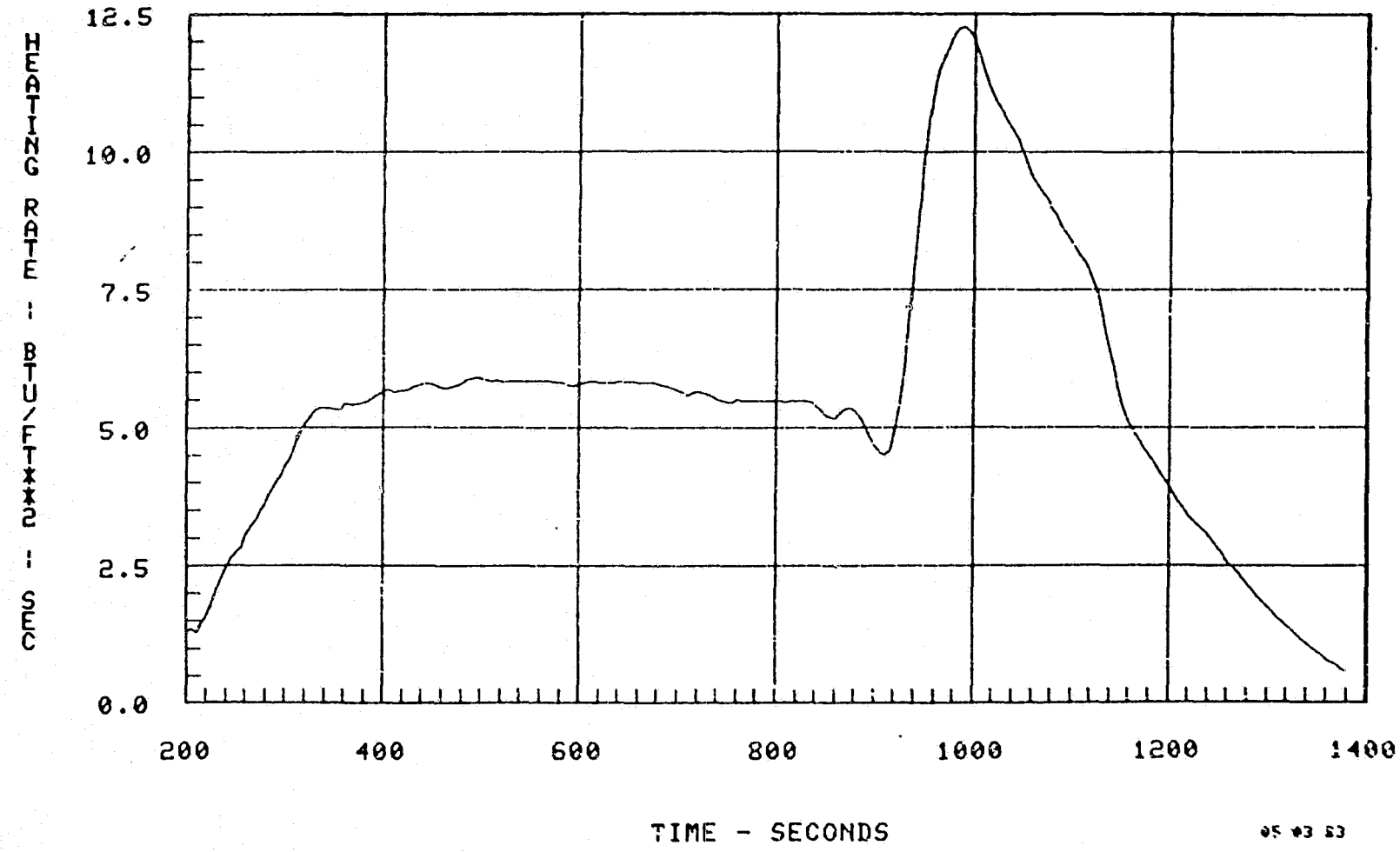

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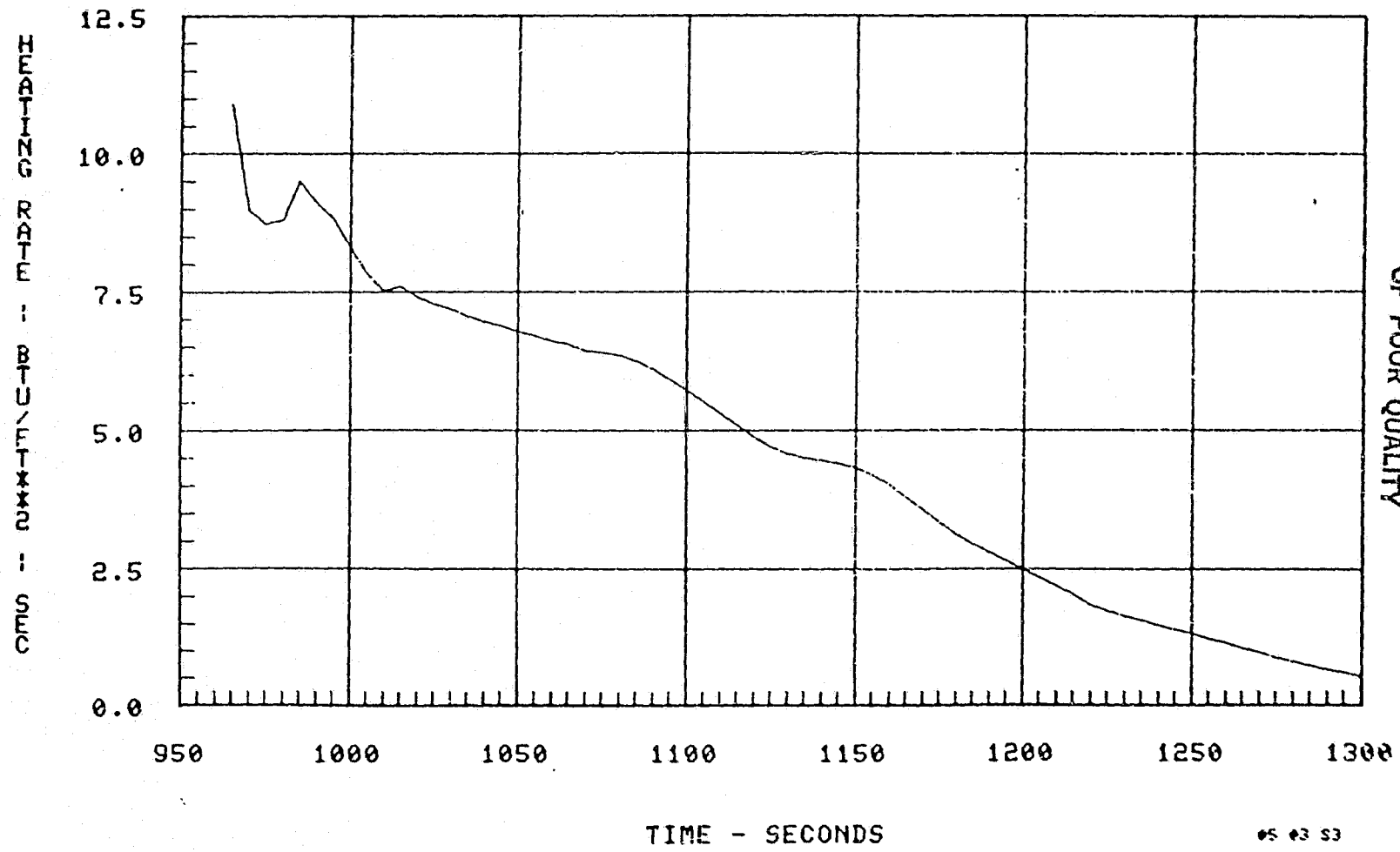

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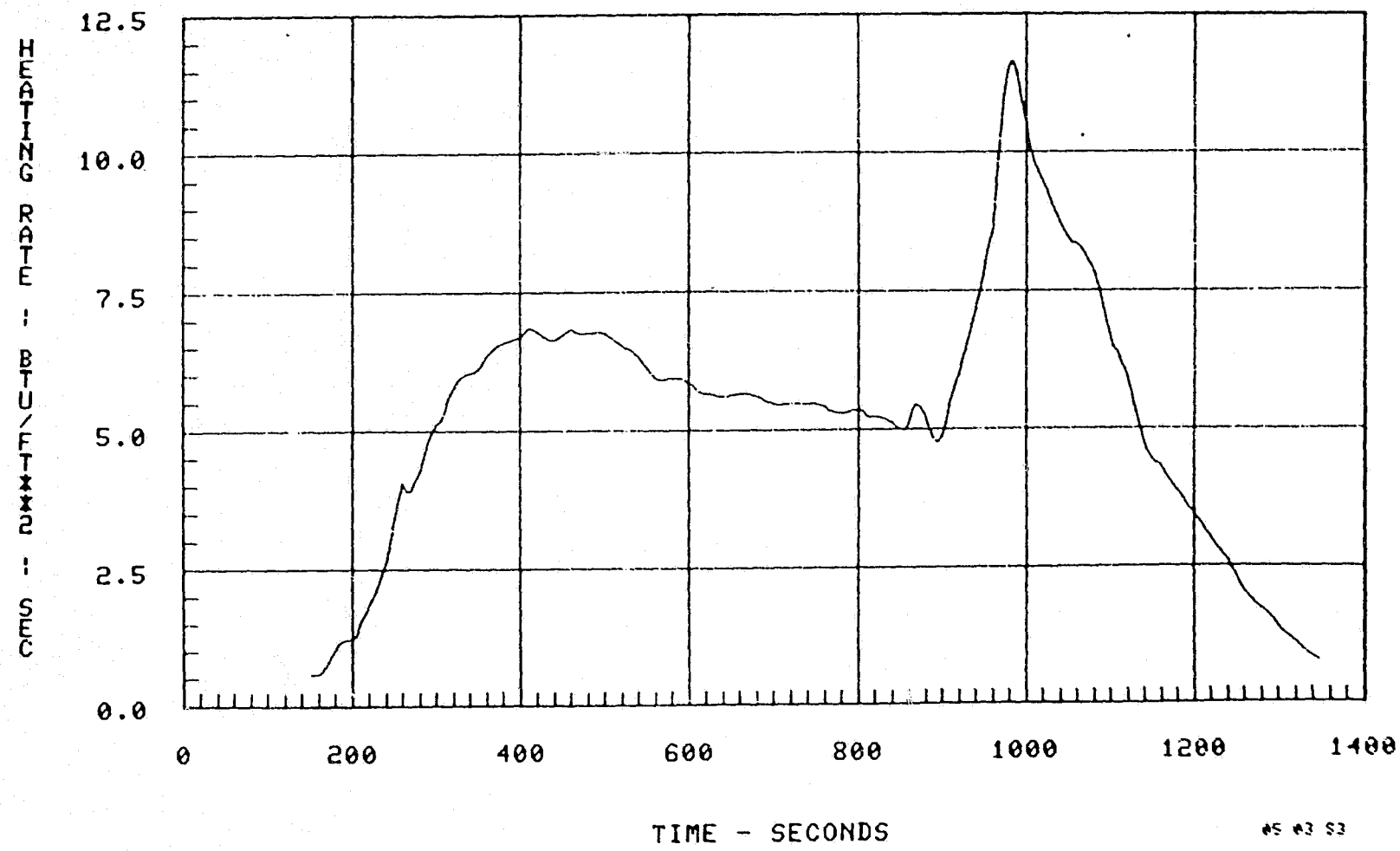

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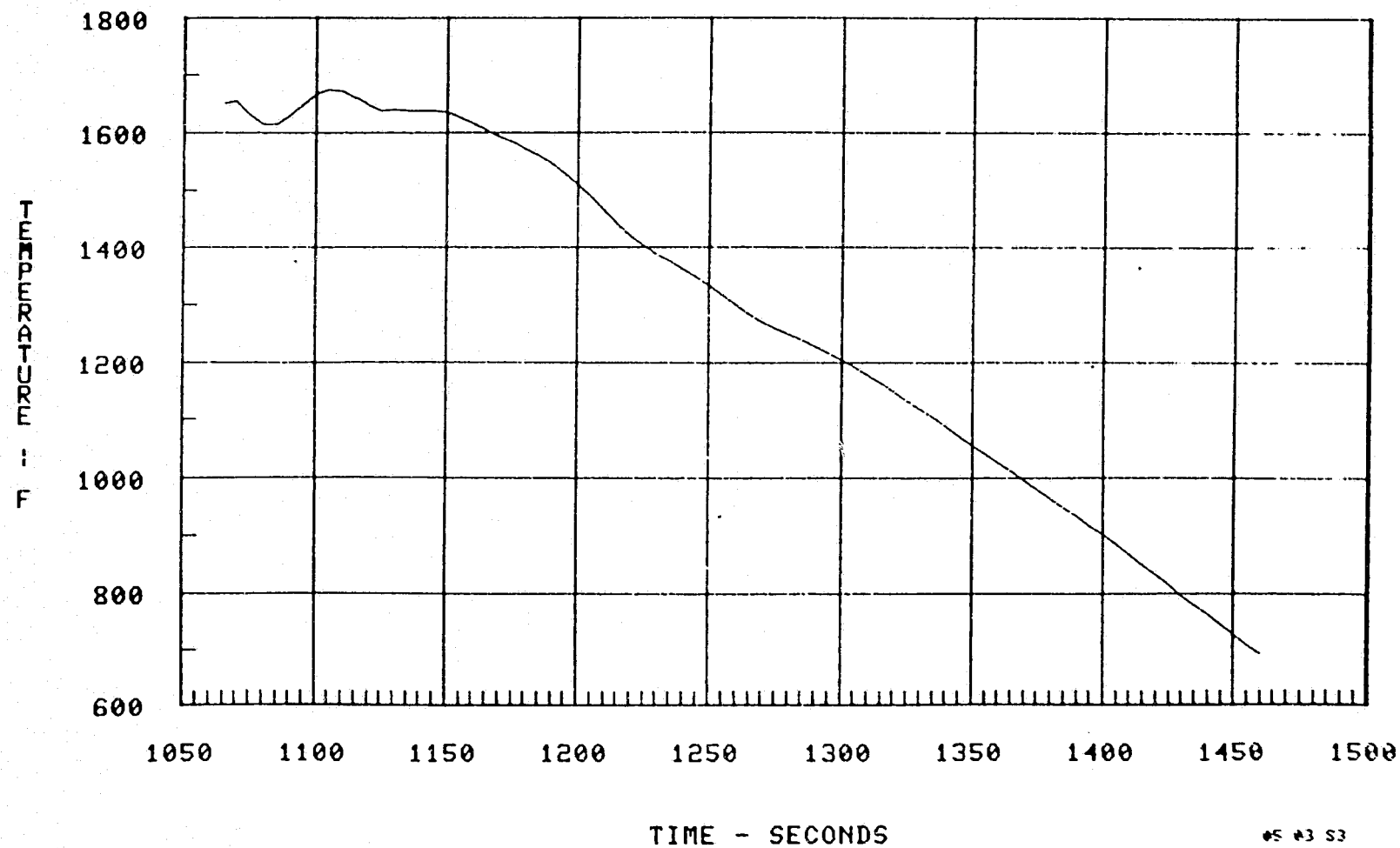

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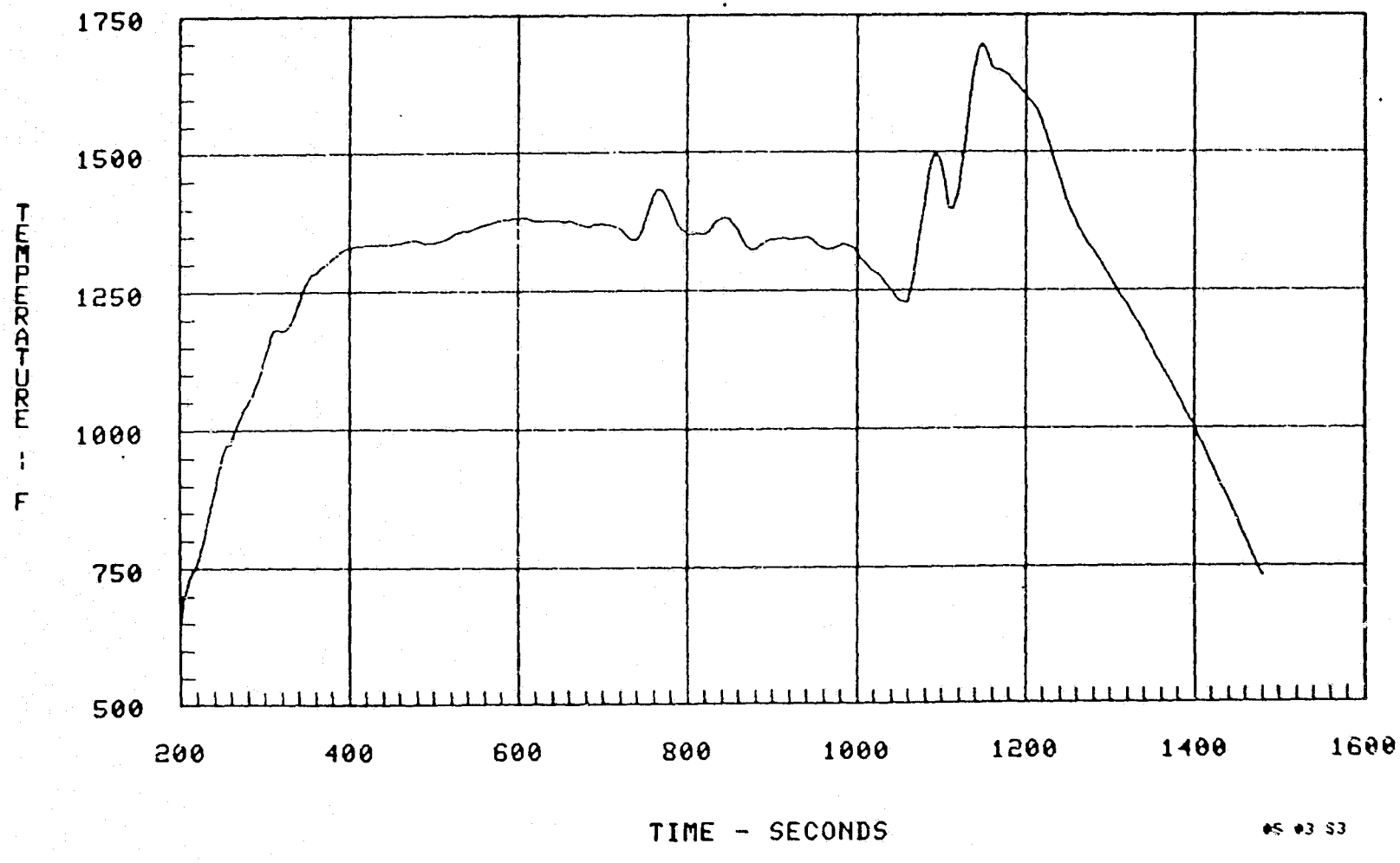

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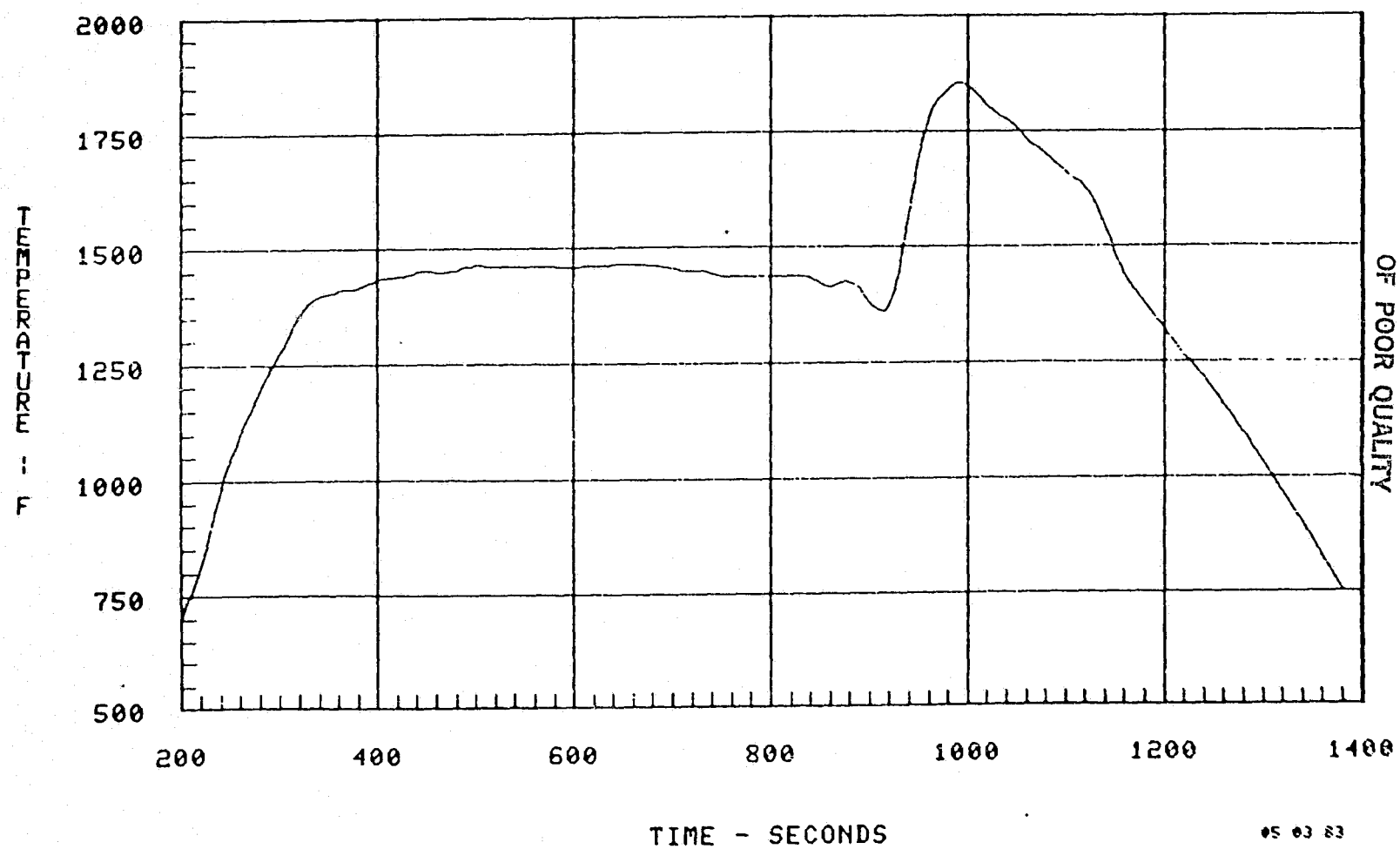

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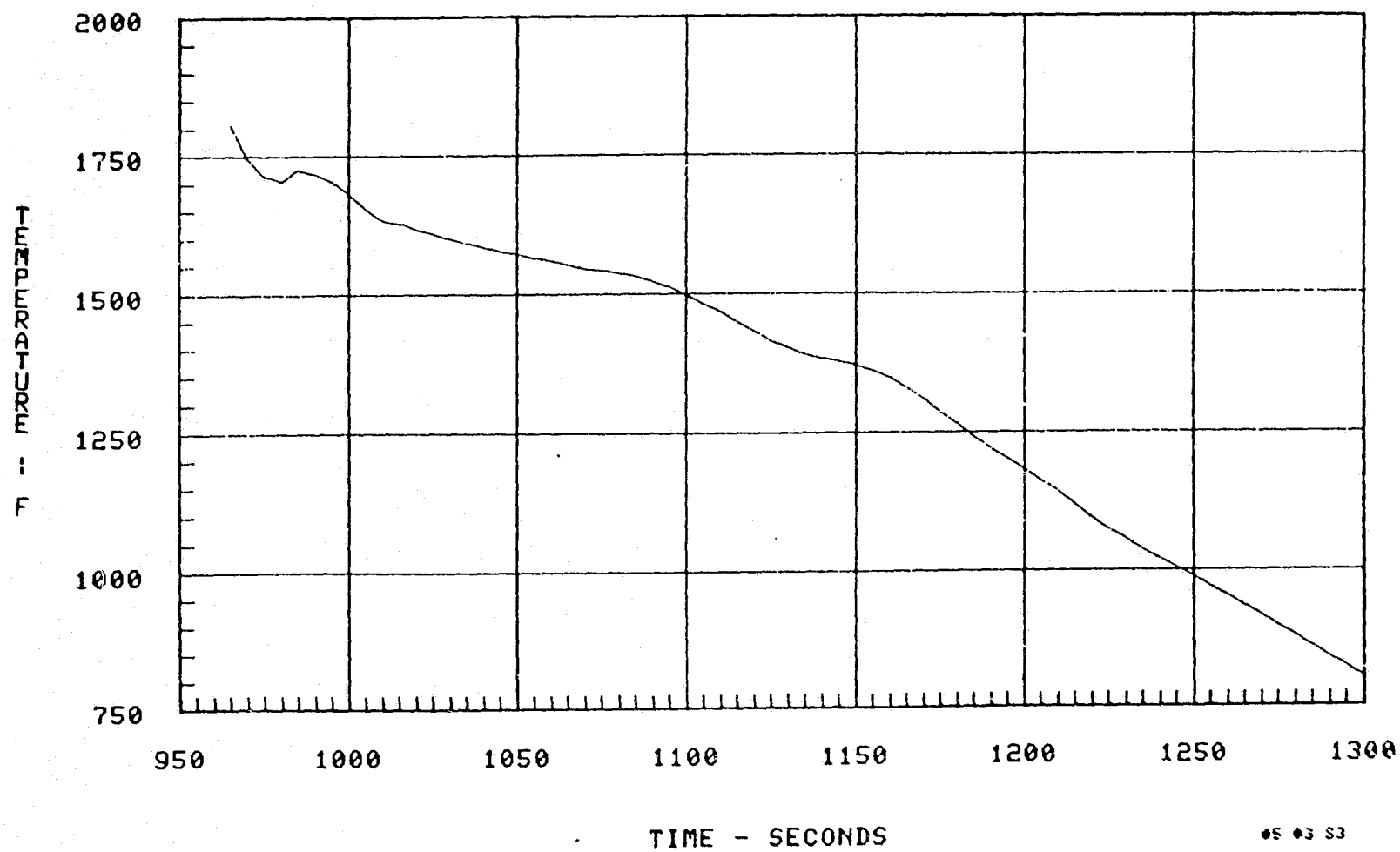

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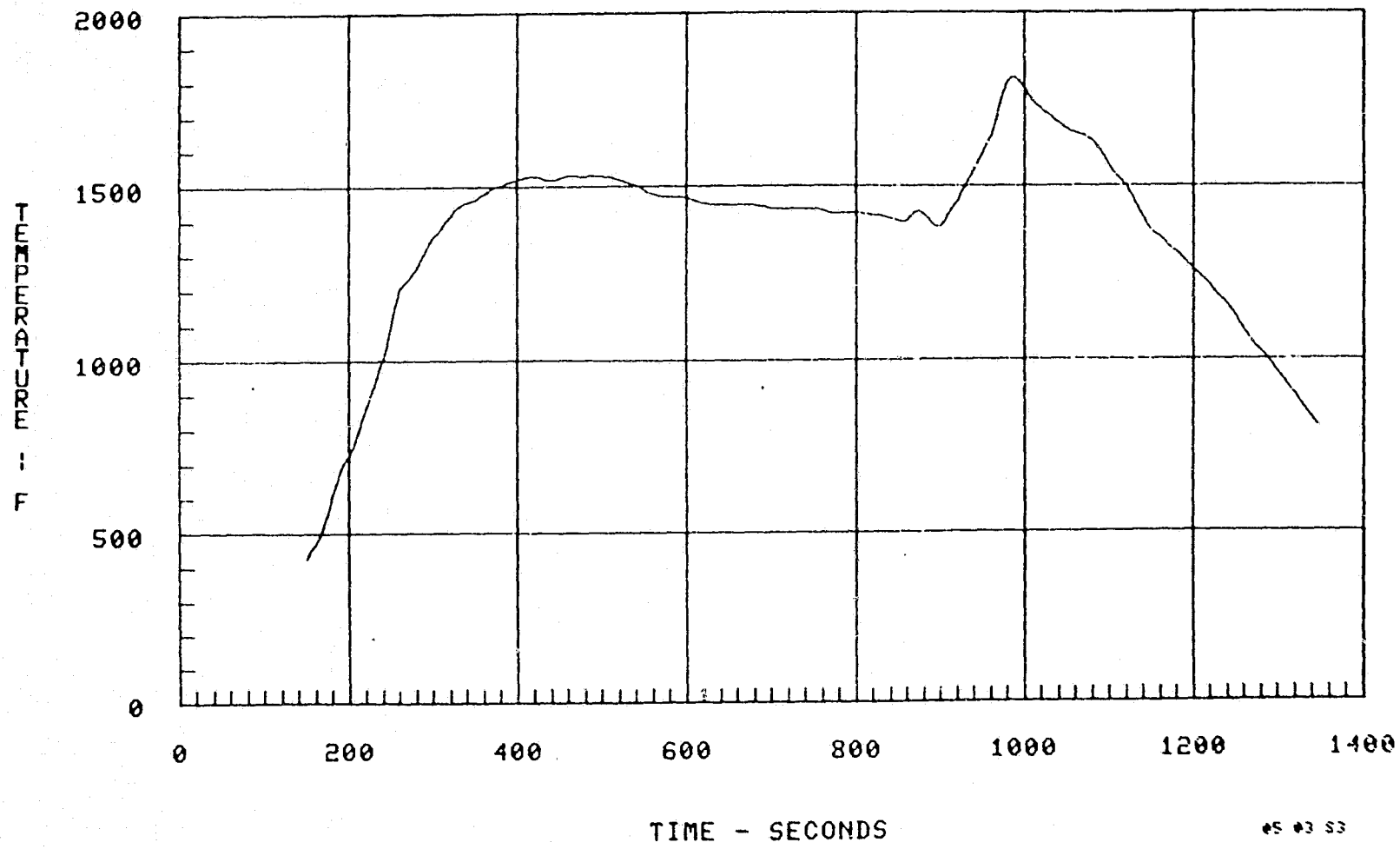

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