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POLYNOMIAL STRICTION ALGORITHMS IN THE DETECTION AND DETERMINATION OF THE CHARACTERISTICS OF NON-STATIONARY PHENOMENA

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16. Abstract

Examined herein is the effectiveness of the algorithm of polynomial striction of the data, and the selection of an algorithm is carried out, according to the results of measurements of the components of the permanent magnetic field in communication sequences from the "Venera-9" space vehicle, where the shock waves were recorded. It is shown that the most effective algorithm, according to the coefficient of striction, is the algorithm of the zero order interpolator (INP). Also examined is the increase in effectiveness with the introduction of a variable threshold of comparison. Calculated herein is the root-mean-square deviation of the error of regeneration of the data with various thresholds, and qualitative analysis of the distortions is carried out, having shown a considerable change in the form of the small discontinuities, which may be interpreted as potential interplanetary shock waves.

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POLYNOMIAL STRICTION ALGORITHMS IN THE DETECTION AND DETERMINATION OF THE CHARACTERISTICS OF NON-STATIONARY PHENOMENA

V. P. Yevdokimov and M. Ya. Natenzon

The task of the detection and measurement of the characteristics of shock waves and explosions in the cosmic plasma, which lead to the non-stationariness of behavior of the physical parameters measured on board a space vehicle, requires provision of the maximum information content of the experiment in the area of the intermittent change in the parameters, and assumes a lesser information content, or even the absence of measurements, in the area of their "calm" behavior. Examined herein is the effectiveness of the algorithm of polynomial striction of the data, and the selection of an algorithm is carried out, according to the results of measurements of the components of the permanent magnetic field in communication sequences from the "Venera-9" space vehicle, where the shock waves were recorded. It is shown that the most effective algorithm, according to the coefficient of striction, is the algorithm of the zero order interpolator (INP). Also examined is the increase in effectiveness with the introduction of a variable threshold of comparison. Calculated herein is the root-mean-square deviation of the error of regeneration of the data with various thresholds, and qualitative analysis of the distortions is carried out, having shown a considerable change in the form of the small discontinuities, which may be interpreted as potential interplanetary shock waves. With a selected magnitude of the threshold l_{γ}, the magnitude of the coefficient of striction proved to be relatively small, and (without taking into account the function information) did not exceed six. /2*

1. Posing of the Problem /3

An important task of space physics, being solved intensively in recent years, is the problem of detection and measurement of the

*Numbers in the margin indicate pagination in the foreign text.

characteristics of the shock waves and explosions in the cosmic plasma, which lead to non-stationariness in the time of the physical parameters measured on board a space vehicle. The object of the study, in the total volume of obtained data, is some moments of intermittent changes in the measured parameter, and the section prior to and after these measurements. The obtaining of a full volume of data with a maximum prescribed frequency of sampling, which provides reproduction of the parameter with guaranteed accuracy, should be ensured in these sections. The utilization of such a high frequency of sampling in sections of "calm" behavior of the parameter is inadvisable, since it considerably increases the volume of information transmitted from onboard the space vehicle.

There occurs the problem of sampling of the information prior to its transmission to earth, which may be solved by two methods:

1. Utilization of a variable frequency of quantization with time, adapted to the behavior of the parameter being studied and ensuring a guaranteed accuracy of reproduction on earth.

2. Detection of non-stationary states of a certain type and transmissions to earth of data only in their vicinities.

The former method is related to the so-called "quasiinvertible" methods of striction of data [1], some of which have been studied in detail, both according to theoretical models [2] and according to a series of experimental data [1], which are related, granted, to the technological parameters of the carrier rocket.

The second method proposes solution of the problem of detection of the non-stationary states aboard the space vehicle.

The solution on the selection of one of these two metnods may be carried out with regard for the preliminary calculation of the coefficient of striction K, which characterizes the decrease in the number of data transmitted to the earth after carrying out of /4 the information sampling.

For the first method, this magnitude is equal to

$$K_c = \frac{N}{N_c \alpha}, \qquad (1)$$

where N is the number of readings of the parameter with cyclic sampling during some time T,

N_c is the number of readings remaining after the procedure of elimination of the excessiveness,

$\alpha > 1$ is the coefficient which shows the increase in the volume of transmitted data, because of the necessity of transmission with striction of the supplementary function information (for recognition and/or temporary tie-in of the readings).

For the second method of sampling, the coefficient of striction is equal to

$$K_c = \frac{N}{n \alpha N_{sec}},$$

where n is the number of non-stationary states of a given type detected during the time T,

N_{sec} is the length of the section, i.e., the number of readings transmitted to earth for each detected non-stationary state.

The number n includes some number of false responses, as a function of the detection algorithm.

Examined in the present study is the first method of data sampling, and comparison and selection of data striction algorithms are carried out according to the results of experimental study of models of striction devices.

A separate study will be devoted to the task of searching for a detection algorithm for realization of the second method.

2. Procedure for Studying and Initial Data

The study of the effectiveness of the data striction algorithms was carried out on the basis of the following three characteristics:

1. The coefficient of striction K_c. /5

2. The root-mean-square error in the readings after the regeneration operation

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}.$$

3. The maximum error in the data after the regeneration operation of the readings discarded as a result of the operation of the striction algorithm: Z.

The first two characteristics were determined as a result of calculations. Also selected were striction algorithms which give a limited magnitude of the maximum error of regeneration. Keeping in mind the necessity of utilizing the results of the given analysis in the experiment on the study of shock waves in the interplanetary and near-planetary plasma, it was decided to carry out calculation of the characteristics of striction on some experimental data which describe the behavior of the plasma near the shock wave. Selected as such data in the first stage of the study were examples of measurements of the three components of the interplanetary magnetic field. These data were obtained using the SG-70 instrument on board the "Venera-9" space vehicle, during its flight in orbit as a satellite of Venus (November 1975-February 1976). Taken for analysis were sequences of communication with recording of the measurements in sections with a duration of from several minutes to several hours, with a frequency of sampling of each component of the magnetic field equal to 1 Hz.

According to the procedure given in [3], we calculated the values of the modulus of the magnetic field, which were also utilized for subsequent analysis.

In accordance with the posed problem, the selected data represented sections in which a near-planet shock wave is distinctly observed, "calm" sections of the interplanetary medium up to the front of the shock wave, and sections of "perturbed" plasma after the front of the shock wave. In addition, nonstationary areas were noted in a number of sequences of communication, in addition to the near-planet shock waves, which may be interpreted as interplanetary shock waves or explosions in the plasma of differing nature. /6

The indicated frequency of sampling makes it possible to not take into account the time constant of the magnetometer, which comprises about 0.25 sec.

Shown in figures 1, 2, 3, and 4 (sequence A) are examples of a shock wave, "calm" and "perturbed" medium, and a potential interplanetary shock wave, and in figures 5 and 6—shock waves in sequences B and C.

The data striction devices, which operate according to different algorithms, were simulated on the computer in the form of program modules. The data for processing were read out from magnetic tape, created as a result of the conduct of the stages of preliminary and primary processing of the telemetric information, obtained in communications sequences from the space vehicle.

3. Data Striction Algorithms

Selected for comparison of effectiveness were three types of polynomial striction algorithms, with an increasing complexity of realization. As is common knowledge, an increase in complexity does not always lead to an increase in effectiveness, which is especially attributed to the striction of actual information; therefore, those studied were [1,2]:

1. zero order forecaster with floating aperture;
2. zero order interpolator;
3. first order interpolator.

These algorithms ensure limitation of the maximum error of regeneration by the prescribed values of ±Z, where we will adopt Z as equal to 1γ or 2γ, keeping in mind that the interplanetary magnetic field usually is 3-10γ ($\gamma=10^{-5}$ oe), the field beyond the shock wave is 10-50γ, and the accuracy of measurements of the magnetometer is 0.5-1γ.

We will examine the logical schemes of the striction algorithms and the methods of regeneration of the sequence of readings according to the condensed data. Insofar as there is no generally-accepted terminology in the designation of algorithms, and because of the great number of their versions, the given logical schemes are sufficiently detailed. /7

Zero Order Forecaster (PNP

1. The reference reading X_i is transmitted.

2. Comparison of the reading difference modulus X_{i+k} (initially, K=1, and the reference reading with a threshold Z is carried out. If $|X_{i+k}-X_i|\leq Z$ actually, then we will move to step 3, or falsely—to step 4.

3. The reading X_{i+k} is considered surplus (passive), K=K+1, we will return to step 2.

4. The reading with the number i+k is considered significant (active), we will move to step 1, where i=i+k.

Regeneration Algorithms

The horizontal lines drawn to the right from each significant reading on the time scale of uncondensed sequence determine the values of all the intermediate surplus readings. The significant readings which run in succession are connected by straight lines.

Maxi-mini Zero Order Interpolator (INP)

1. The reading X_i is taken. The value of X_i is assigned to the variables MAX, MIN, which designate the maximum and minimum values from the sequence of readings:

$$MAX=X_i$$
$$MIN=X_i$$

2. The next reading X_{i+k} is taken, where K=1 initially.

3. A search is conducted for a new maximum value in the group (MAX, X_{i+k}), and this value is assigned to the variable MAX. A search is conducted for a new minimum in the group (MIN, X_{i+K}), and this value is assigned to the variable MIN. /8

4. Verification of the activity in the group K+1 of readings is carried out. If (MAX-MIN)·2Z actually, we will move to step 5, or falsely—to step 6.

5. An evaluation is formulated of the group of passive readings, equal to

$$EST = (MAX + MIN)/2.$$

   K is changed to K+1, and we return to step 2.

6. The group of passive readings is terminated. The value of EST is transmitted, which represents the group of K-1 passive readings, 1=1+K, and we return to step 1.

Regeneration Algorithms

Drawn on the time scale of uncondensed sequence of readings are horizontal straight lines, which determine the values of all passive readings to the left of each transmitted value prior to the preceding transmitted value.

<u>First Order Interpolator (IPP) With Transmission of the Value</u>

1. The initial reference reading X_1 is transmitted. We will move to step 3.

2. X_i is transmitted as a reference reading.

3. The upper and lower increments are calculated (with i=1, $X_i = X_1$):

$$\Delta_B = X_{i+1} + Z - \hat{X}_i,$$
$$\Delta_H = X_{+1} - Z - \hat{X}_i.$$

4. The upper and lower values of the reading with the number i+k are formulated (initially, K=2):

$$\hat{X}^B_{i+K} = X_i + K\Delta_B,$$
$$\hat{X}^H_{i+K} = X_i + K\Delta_H.$$

5. Verification of the activity of the reading X_{i+k} is accomplished. If /9

$$(\hat{X}^B_{i+K} < X_{i+K} - Z) \vee (\hat{X}^H_{i+K} > X_{i+K} + Z),$$

actually, we will move to step 6, or falsely—to step 7.

6. The reading X_{i+k} is considered active, i=i+k-1. If K=2, then $X_i = X_i$. We will return to step 2.

7. The reading X_{i+k} is considered passive. Verification of the mutual location of the upper value X^B_{i+k} and $(X_{i+k}+Z)$ is accomplished. If $X^B_{i+k} > X_{i+k}+Z$ actually, we will move to step 8, or falsely—to step 9.

8. Adopted as a new value of the upper value is

$$\hat{X}^B_{i+k} = X_{i+k} + Z.$$

The new value of the upper increment is calculated:

$$\Delta_B = (\hat{X}^B_{i+k} - \hat{X}_i)/K.$$

9. Verification of the mutual location of the lower value is accomplished

$$X^H_{i+k} \text{ and } (X_{i+k} - Z).$$

If X^H_{i+k} $X_{i+k}-Z$ actually, we will move to step 10, or falsely—to step 11.

10. Adopted as a new value of the lower value is

$$\hat{X}^H_{i+k} = X_{i+k} - Z.$$

The new value of the lower increment is calculated:

$$\Delta_H = (\hat{X}^H_{i+k} - \hat{X}_i)/K.$$

11. The value of the last of the series K of surplus readings is calculated

[illegible],

K=K+1, we will return to step 4.

Regeneration Algorithms /10

The straight lines which connect the transmittable active readings on the time scale of uncondensed sequence determine the values of all the intermediate surplus readings.

Also studied, in addition to these algorithms, were two of their modifications, namely, the forecaster and interpolator of zero order, with a variable threshold.

For PNP, the modification amounted to the following. With a value of the reference reading $X_i \leq 10\gamma$, no changes whatsoever took place. With $X_i > 10\gamma$, the magnitude 0.1 X_i was utilized in step 2 in place of the magnitude Z, i.e., the threshold was equal to 10% of the reference reading.

For INP, the modification was somewhat more complex. In step 1, the assignment of the value of the initial reading X_i to the value EST is added. In step 4, if EST $\leq 10\gamma$, then the changes are not introduced, whereas if EST $> 10\gamma$, then the magnitude equal to $0.1(\frac{MAX+MIN}{2})$ is utilized instead of the magnitude Z. This corresponds to the designation of a threshold equal to 10% of the new value of the reading evaluation.

Thus, with values of the parameter greater than 10γ, the magnitude of the threshold Z increases proportional to the increase in the values of the magnetic field, which leads to an increase in the coefficient of striction. It is natural that, in this case, the absolute value of the regeneration error will be greater the greater the magnitude of the reading.

4. Results and Conclusions

The values of the coefficients of striction, without taking into account the function information, i.e., with $\iota=1$, and the root-mean-square errors of regeneration, obtained as a result of calculation according to three communications sequences from "Venera-9" for all of the studied algorithms, are given in tables 1, 2, and 3. Recorded in each of these sequences is a shock wave, and the nature of the behavior of the magnetic field in "calm" sections is different. Sequences A and B were the most positive, /11
and each of them contained long sections of "calm" and "perturbed" medium, with the "calm" section in sequence A having a much more variable nature than that in sequence B. Sequence C contained practically only small sections on both sides of the front of the shock wave, which had a substantial influence on the calculated values of the coefficients of striction. For the possibility of separate analysis, the coefficient of striction and the error were

calculated both according to the entire sequence, and according to the "calm" section, which includes the entire volume of data on the interplanetary medium from the boundary of the sequence to the front of the near-planet shock wave, and the "perturbed" section, which contains data on the hot plasma from the front of the shock wave to the other boundary of the sequence.

The calculations according to the algorithms with a variable threshold were carried out only for sequence A, and only for the case when, with a magnitude of the magnetic field less than 10_γ, the threshold Z was equal to 1_γ. Comparison of the coefficients of striction shows that, of the three algorithms (PNP, INP, IPP), the greatest coefficient of striction is provided by the zero order interpolator—INP. In sequence A, the magnitude of the advantage, with respect to the first order interpolator, is equal to 1.43 with $Z=1_\gamma$, and 2 with $Z=2_\gamma$, and, with respect to the zero order forecaster—1.9 with $Z=1_\gamma$, and 2.2 with $Z=2_\gamma$. The magnitude of the advantage of the first order interpolator relative to the forecaster is small, which corroborates the conclusion, drawn earlier [2], on the inadvisability of the utilization of a sufficiently complex IPP algorithm. At the same time, the complication of the algorithm for the realization of the zero order interpolator, which is slight as compared with PNP, leads to a perceptible increase in the coefficient of striction, and makes it possible to show preference to it.

Separate calculations of the coefficients of striction for "calm" and "perturbed" sections in sequences A and B show that the effectiveness of striction is sharply different for them. In /12 sequence A, in the "calm" section, the coefficient of striction increases by 1.9 times with $Z=1_\gamma$, and 6.7 times with $Z=2_\gamma$. For sequence B, the "calm" section is characterized by a practically constant average value and a small dispersion; therefore, the difference in the sections is more considerable for it: the coefficient of striction in the calm section increases by 2 times with $Z=1_\gamma$, and by 10 times with $Z=2_\gamma$. At the same time, the coefficients of striction throughout the sequence differ slightly.

The results for algorithms with a variable threshold show a slight (by 1.25 times for INP) increase in the coefficient of striction. This is explained by the fact that the basic contribution to the magnitude of the coefficient of striction throughout the sequence is made by the "calm" section, where the magnetic field is appreciably less than 10γ, and the threshold Z does not change. This makes it possible to draw a conclusion on the inadvisability of utilization of algorithms with a variable threshold in the given case.

In addition to the magnitude of the coefficient of striction and the root-mean-square error, finer analysis of the distortions of the form of the signal, occurring after regeneration, is required for evaluation of the effectiveness of the examined "quasiinvertible" methods for reducing the excessiveness. These distortions are illustrated by figures 7, 8, 9, and 10, where the same sections are shown as in figures 1, 2, 3, and 4, respectively, after regeneration of the data, condensed by the zero order interpolator with a threshold Z=1γ, and figures 11, 12, 13, and 14, for the threshold 2γ. We will note some clear-cut features of the regenerated data. First, the feature in the magnetic field, which looks like a potential interplanetary shock wave in figure 4, practically disappears in figures 10 and 14. In addition, that portion of the data directly preceding the sharp increase in the magnetic field in figure 1, i.e., the front of the wave, is strongly distorted. In this connection, under actual conditions, it is inadvisable to /13 make use, evidently, of the magnitude of the threshold Z=2γ. With a threshold Z=1γ, the magnitude of the coefficient of striction throughout the sequence did not exceed K_c=6.38. Taking into account the fact that still another reading, which shows the current time of the measurement in the interval T, accompanies each reading of the parameter during realization of the algorithm of striction, we obtain ι≥2 in formula (1). In this case, the actual coefficient of striction for the sequence does not exceed the magnitude 3.19. The root-mean-square error of regeneration of the readings does not exceed the magnitude 0.314γ in this case, with a permissible maximum error of ±1%. The obtained magnitude of the coefficient of striction is not very great, although one can nevertheless consider the presentation to the experimenter of information on the behavior of the parameter throughout the sequence, and not only in the area of the non-stationary state, an advantage of the use of polynomial algorithms.

Evaluation of the competitiveness of polynomial algorithms of striction, relative to methods of detection, can be carried out, utilizing formula (2), from the following considerations. With the transmission of data along a single loop of the planet satellite, the space vehicle twice intersects the near-planet shock wave, i.e., $n \geq 2$. Given a maximum volume of data, which may be recorded on board the space vehicle, and a volume of data which corresponds to a single section of the non-stationary area, having evoked response of the detection algorithm, we can determine the maximum number of recorded sections of the non-stationary area. Hence, we obtain the minimum value of the coefficient of data striction, which we can compare with the values which correspond to the polynomial algorithms. The comparison of the methods of striction will be carried out in the second part of the study.

In conclusion, the authors express their gratitude to Candidate of Physical and Mathematical Sciences G. I. Zastenker for his useful discussions on posing of the problem and the results, to Candidate of Physical and Mathematical Sciences Ye. G. Yeroshenko for his submission of data and help in sampling of the actual /14
information, and Candidate of Technical Sciences V. F. Babkin for his participation in the discussion of the results.

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/15

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SEQUENCE A

TABLE 1

	a порог I гамма							b порог 2 гамма					
	c ПНП	d ПНП с перем порогом	e ИПП	f ИНП волна	g ИНП	h ИНП с перем порогом	i ИНП фон	j ИНП волна	k ПНП	l ИПП	m ИНП	n ИНП фон
o коэффициент сжатия	3,I6	3,8I	4,I5	4,89	5,93	7,25	9,33	5,9I	7,56	8,42	I6,9	39,8
p, ско ошибки	0,I92	0,466	0,344	0,557	0,303	0,608	0,3I2	0,742	0,[illegible]	I,3	I,03	0,923

Key:
a. Threshold 1 gamma
b. Threshold 2 gamma
c. PNP
d. PNP with variable threshold
e. IPP
f. INP wave
g. INP
h. INP with variable threshold
i. INP background
j. INP wave
k. PNP
l. IPP
m. INP
n. INP background
o. Coefficient of striction
p. Root-mean-square deviation of error

SEQUENCE B TABLE 2

	a порог I гамма			b порог 2 гамма		
	c ПНП	d ИПП	e ИНП	f ПЧП	g ИПП	h ИНП
i коэффициент сжатия	I,93	2,49	2,94	3,37	4,4I	5,09
j ско ошибки	0,0782	0,303	0,267	0,625	I,II	0,9II

SEQUENCE C TABLE 3

	a порог I гамма			b порог 2 гамма		
	ИНП e	ИНП k волна	ИНП l фон	ИНП e	ИНП k волна	ИНП l фон
i коэффициент сжатия	6,38	5,II	I0,5	23,I	I5,2	I52
j ско ошибки	0,3I4	0,32I	0,302	0,82	I,03	0,472

Key:
a. Threshold 1 gamma
b. Threshold 2 gamma
c. PNP
d. IPP
e. INP
f. PNP
g. IPP
h. INP
i. Coefficient of striction
j. Root-mean-square deviation of error
k. INP wave
l. INP background

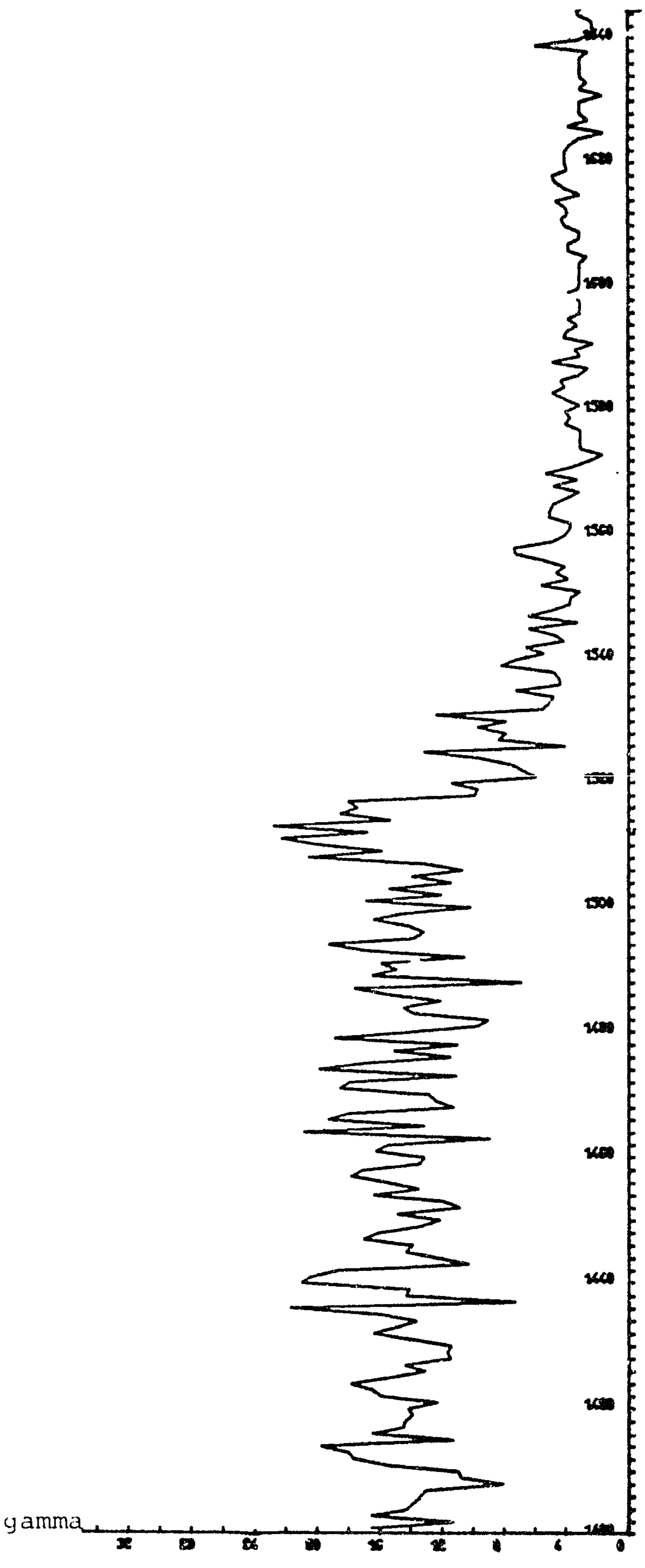

Fig. 1. Shock wave. Sequence A. 11/1/75.

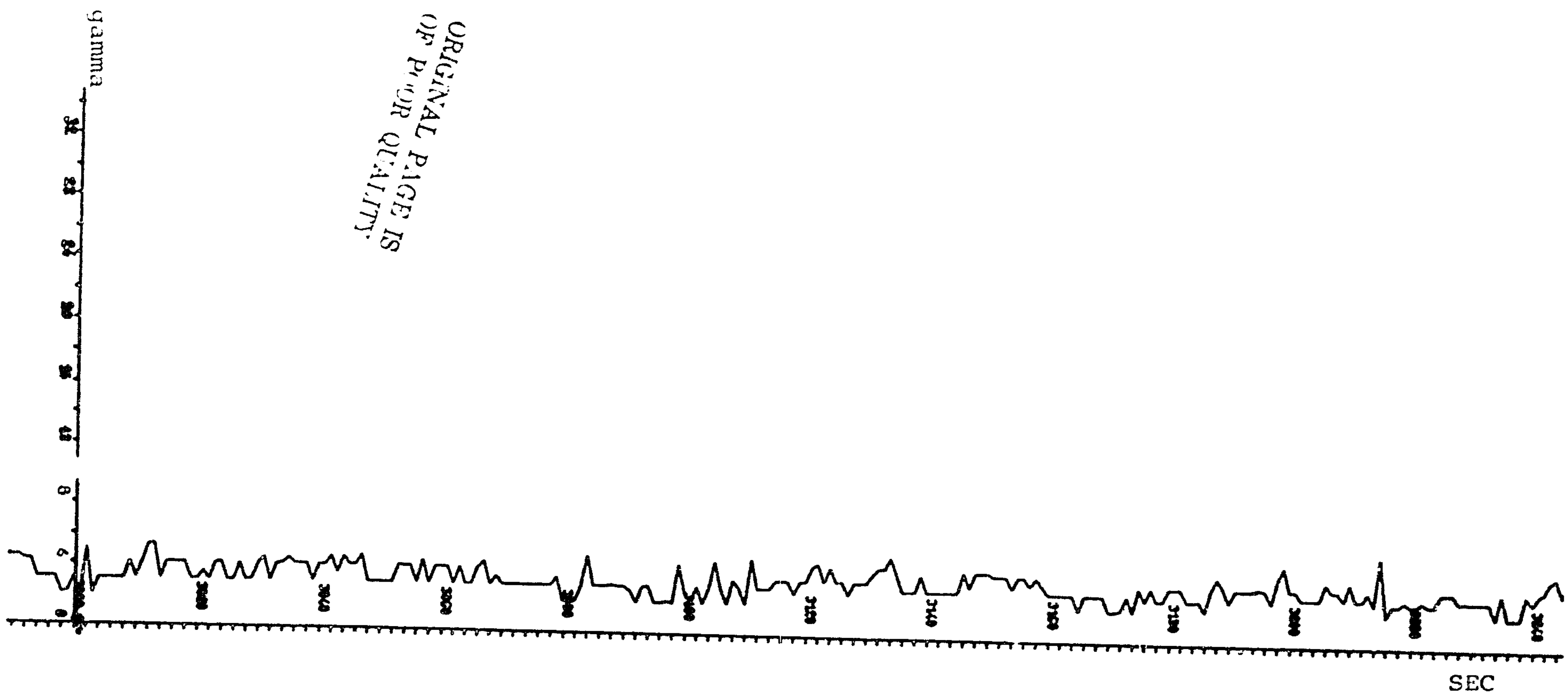

Fig. 2. Section of "calm" magnetic field. Sequence A.
11/1/75.

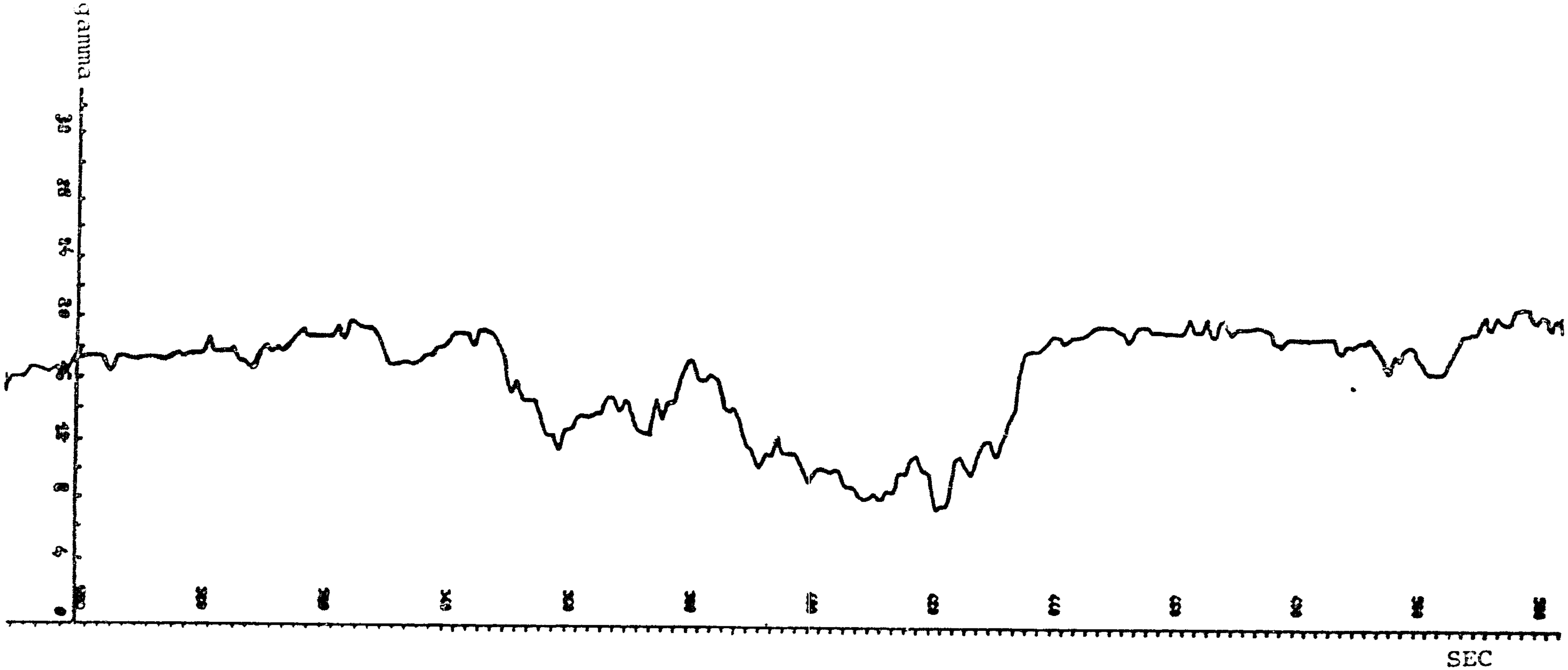

Fig. 3. Section of "perturbed" medium beyond shock wave. Sequence A.
11/1/75.

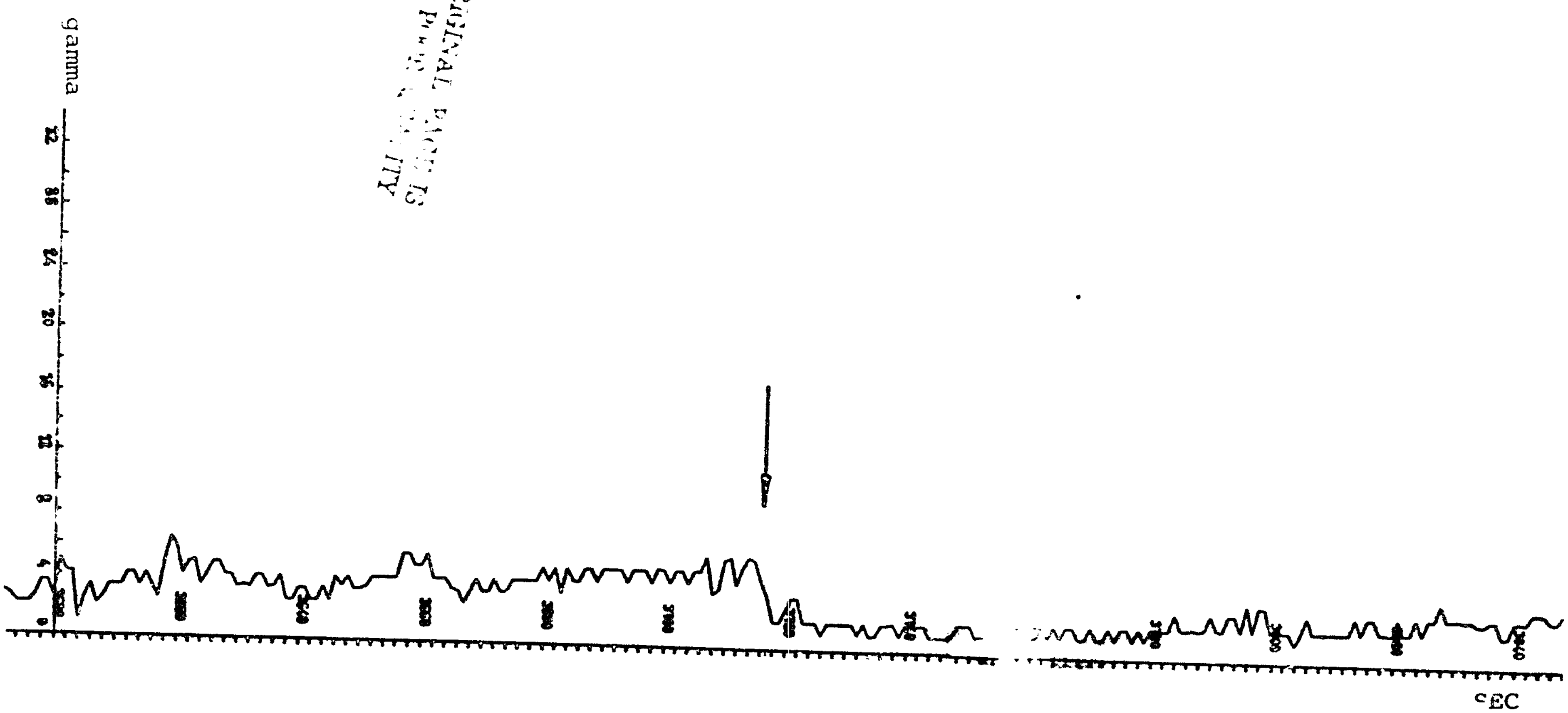

Fig. 4. Possible interplanetary shock wave. Sequence A. 11/1/75.

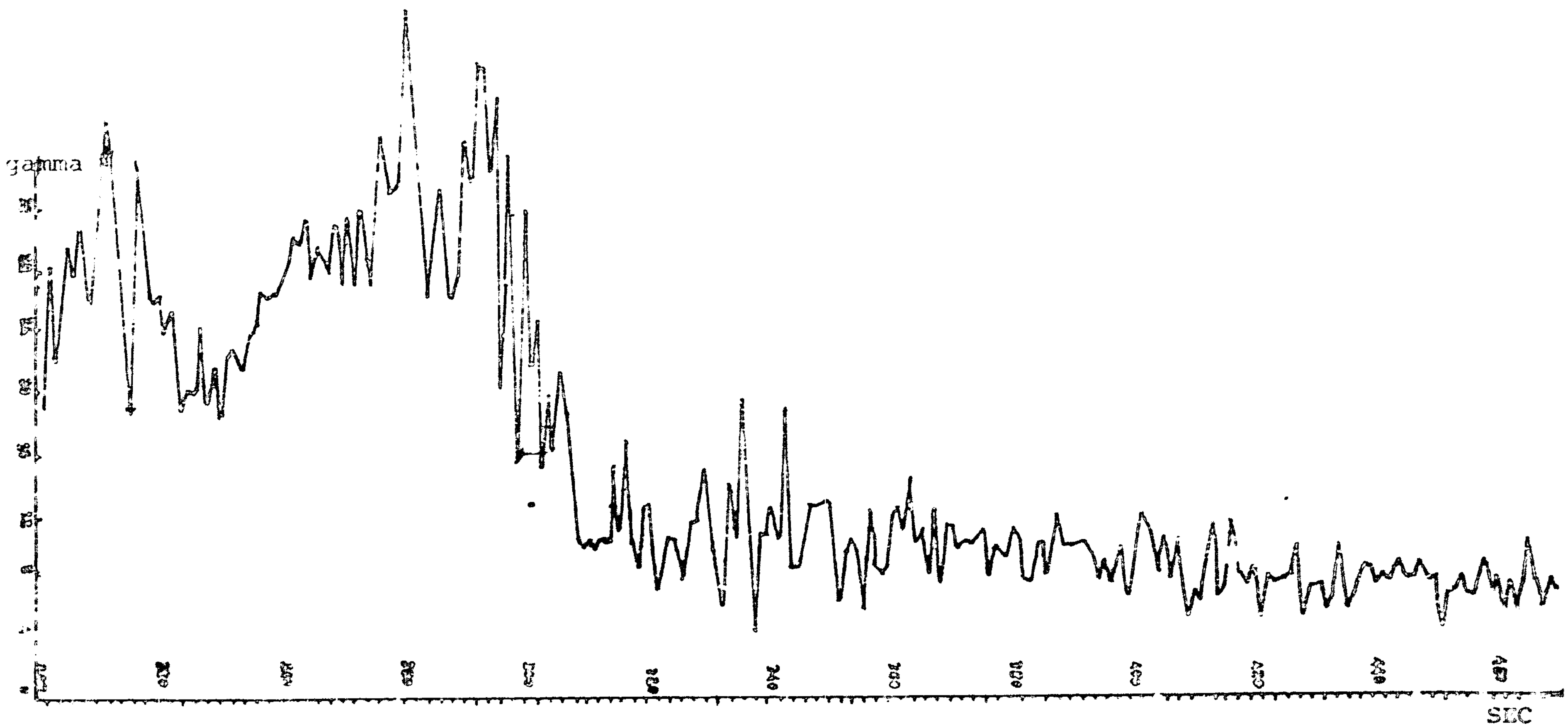

Fig. 5. Sequence B. 11/17/75

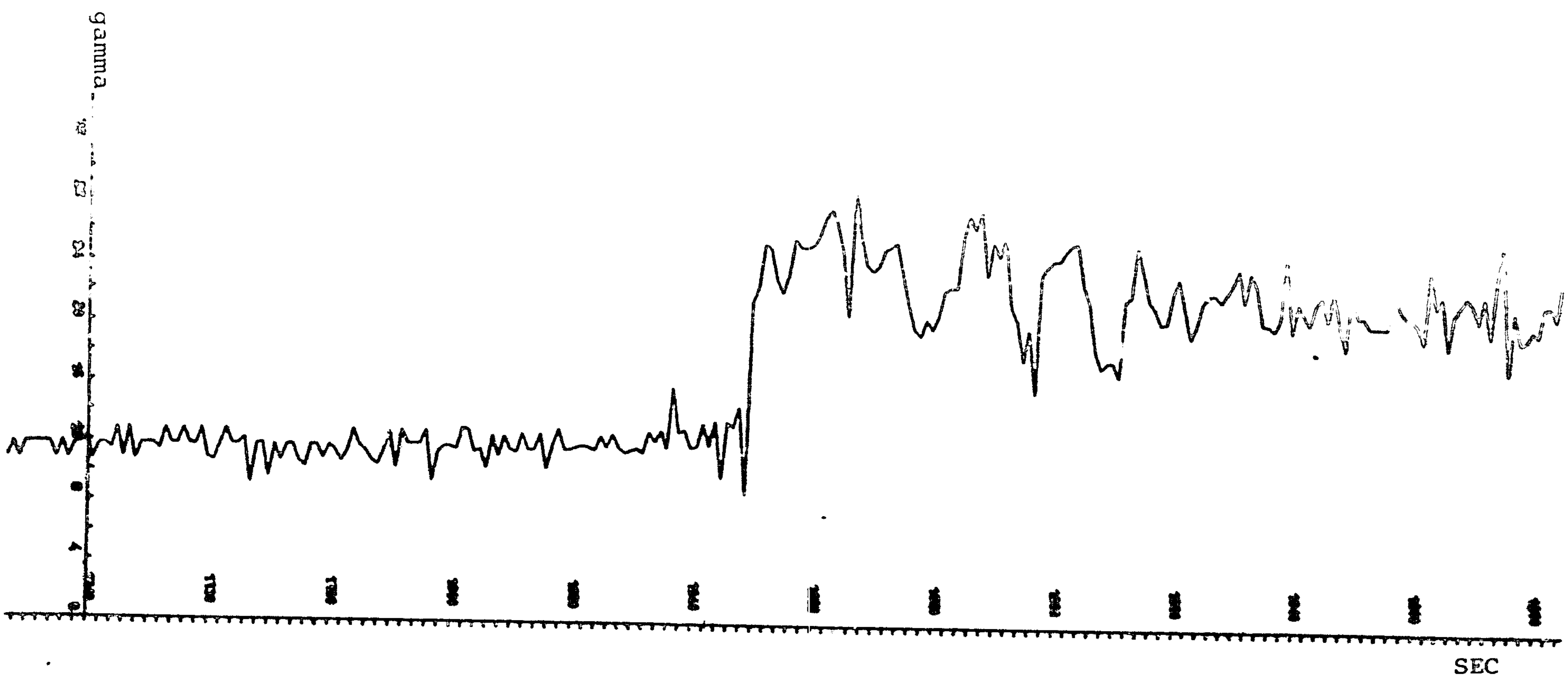

Fig. 6. Sequence C. 12/17/75.

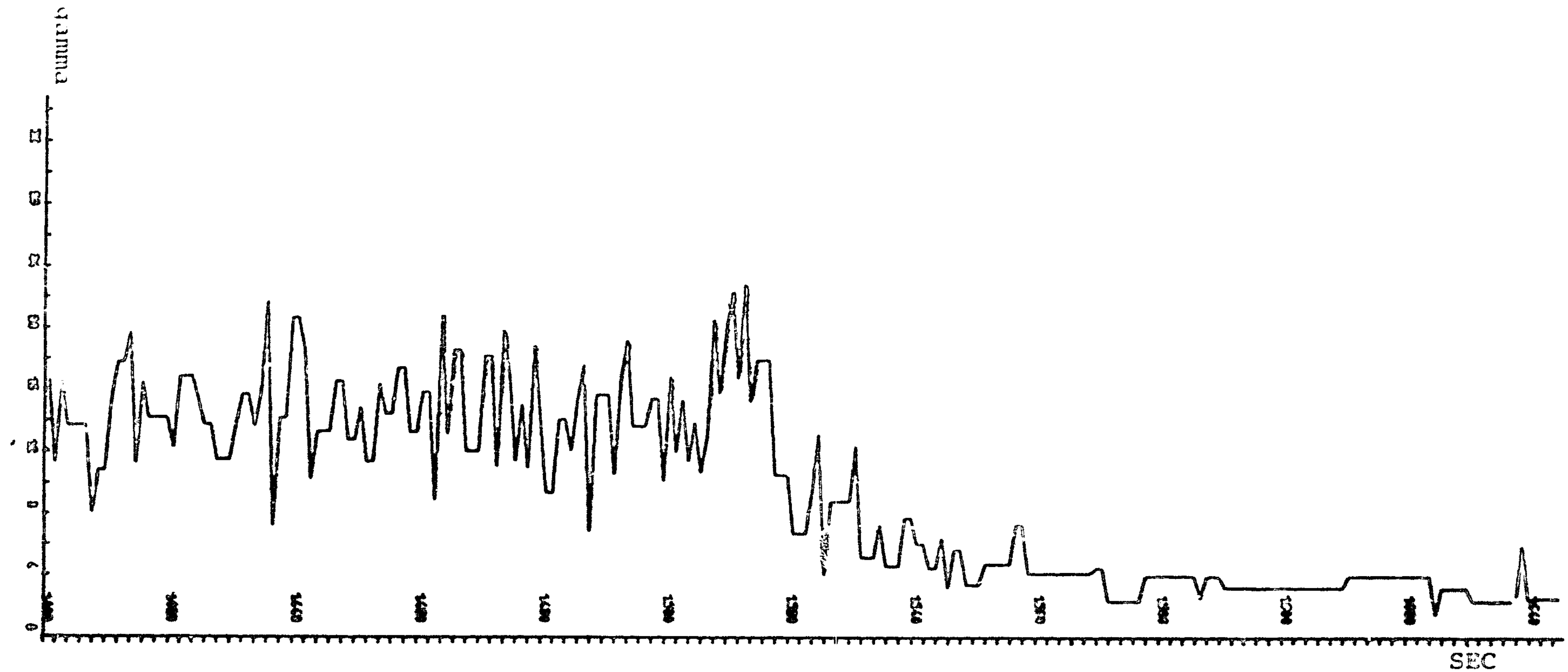

Fig. 7. Threshold 1 gamma.

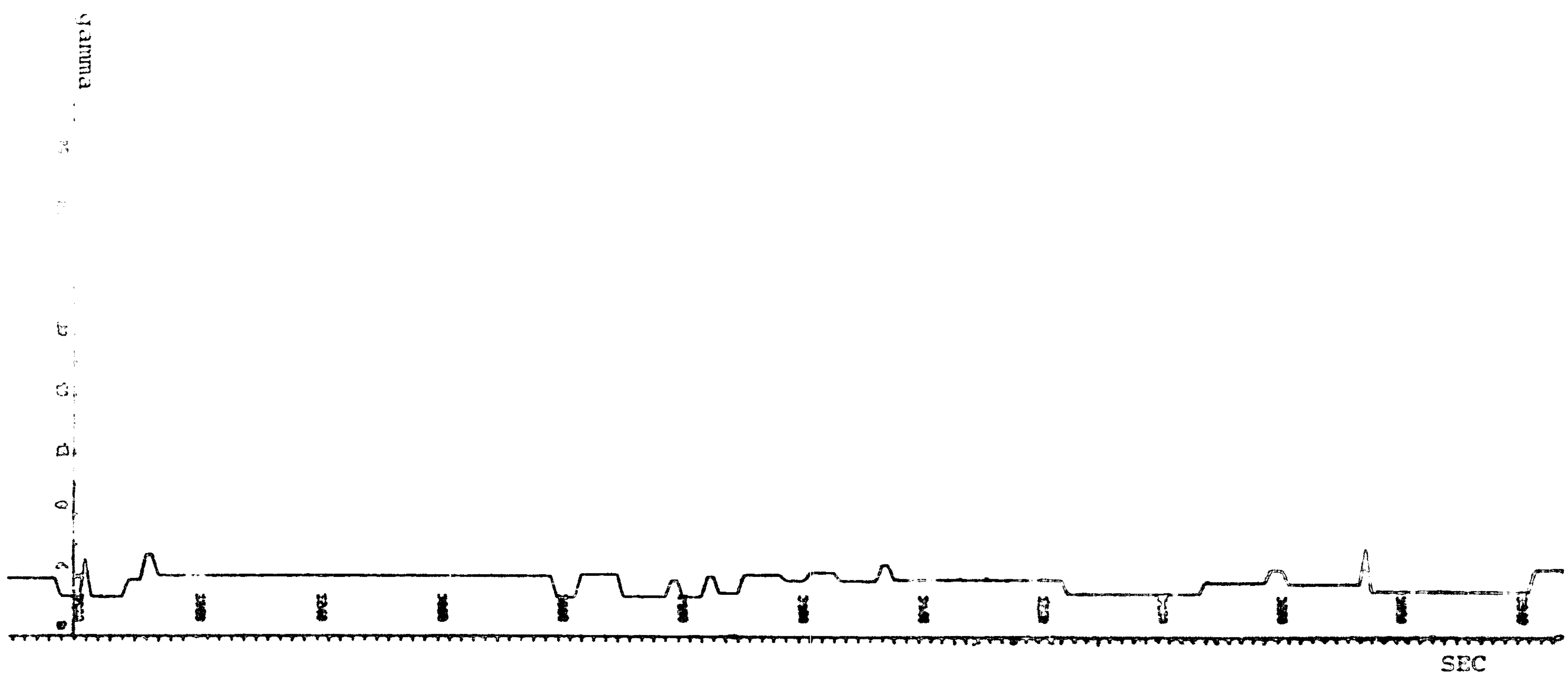

Fig. 8. Threshold 1 gamma

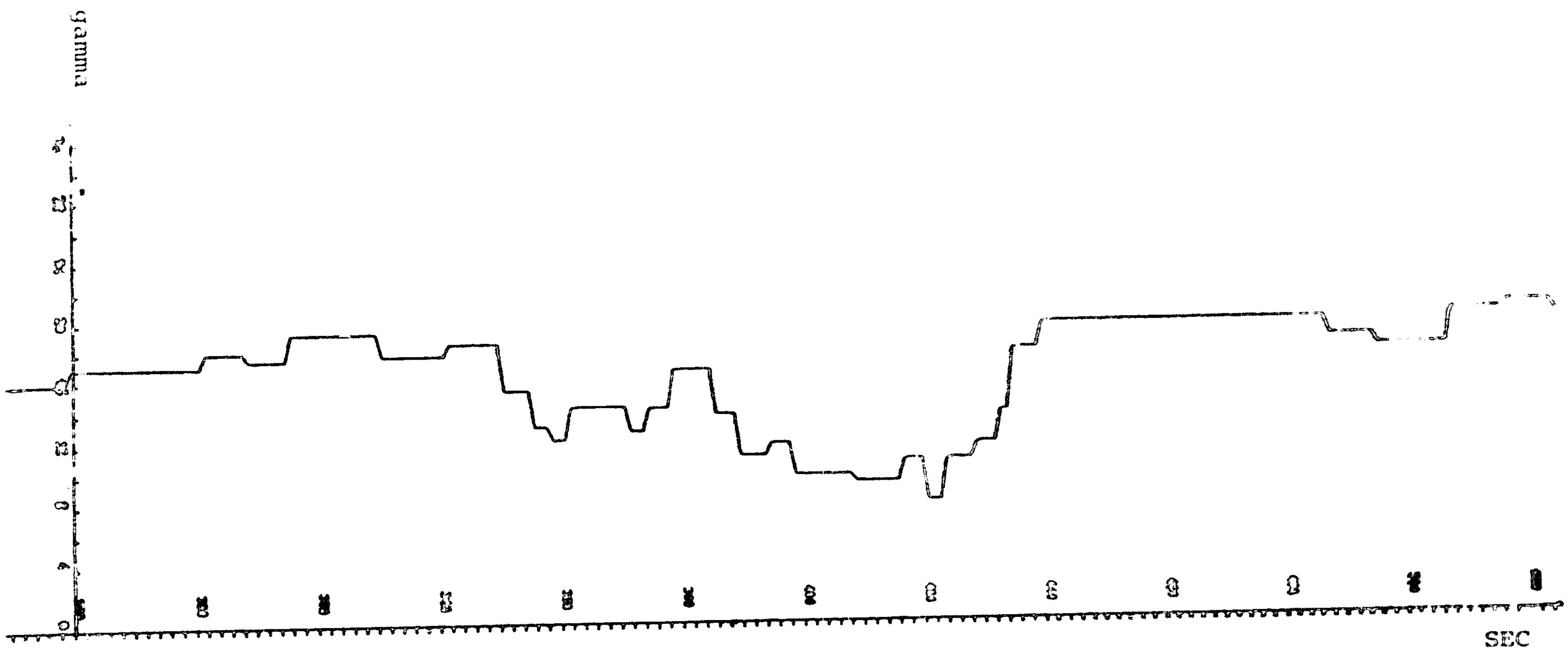

Fig. 9. Threshold 1 gamma.

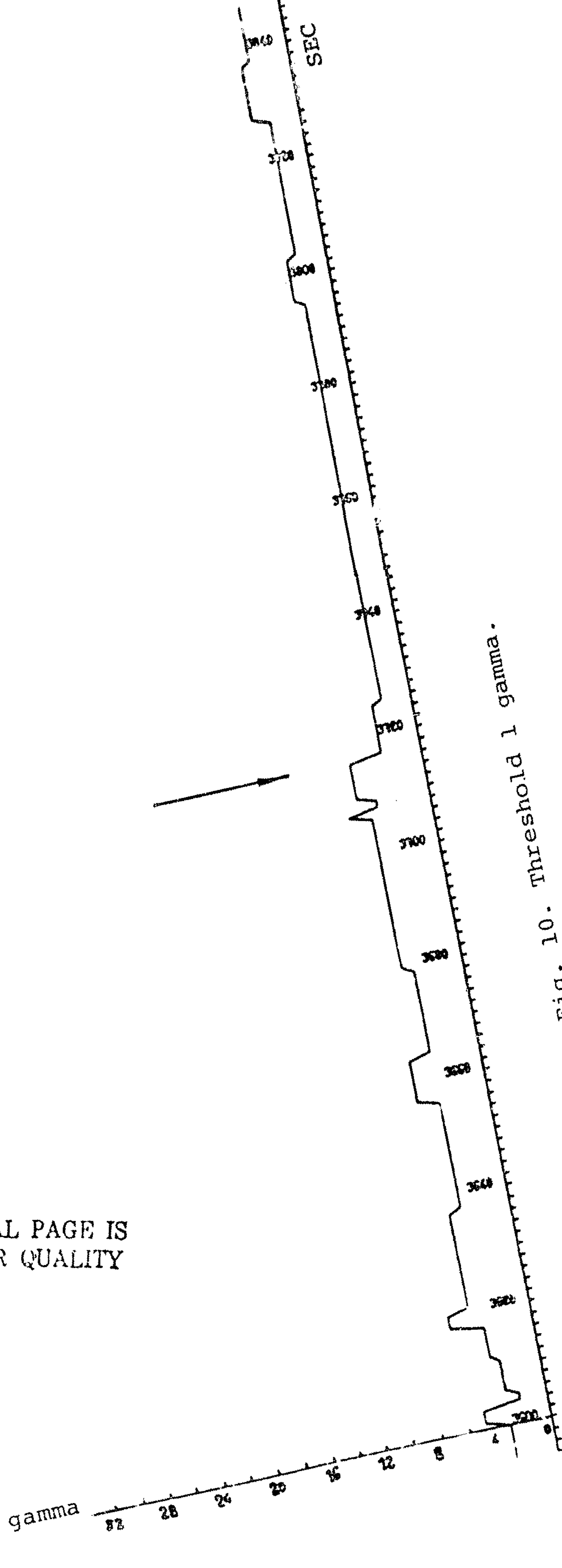

Fig. 10. Threshold 1 gamma.

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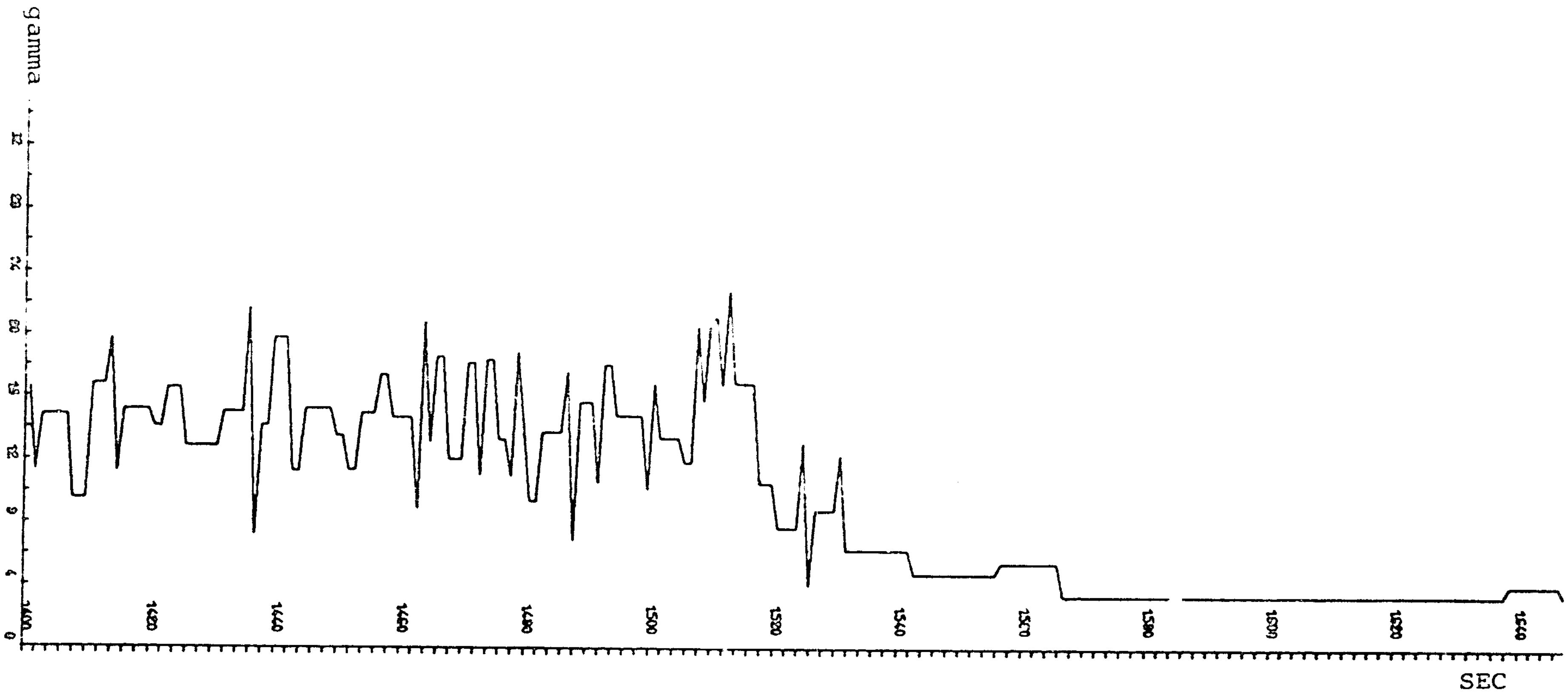

Fig. 11. Threshold 2 gamma.

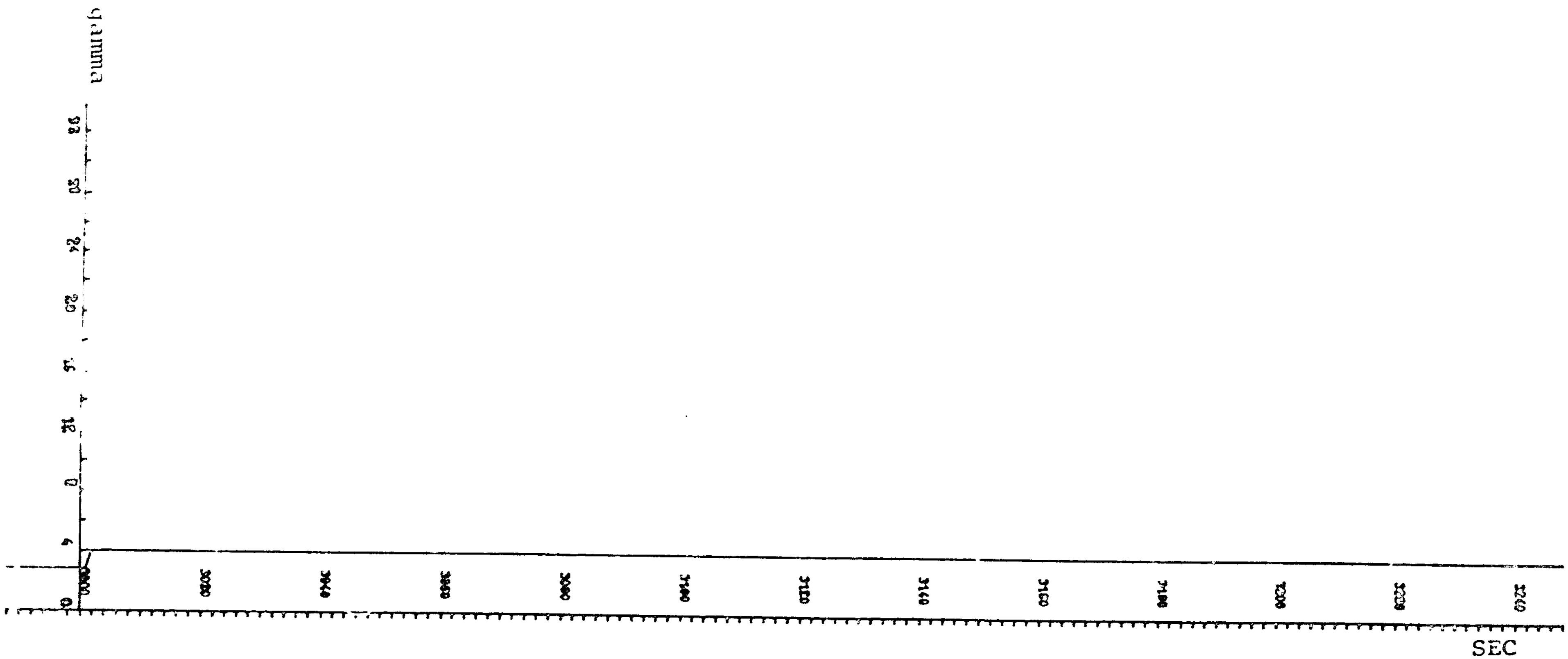

Fig. 12. Threshold 2 gamma.

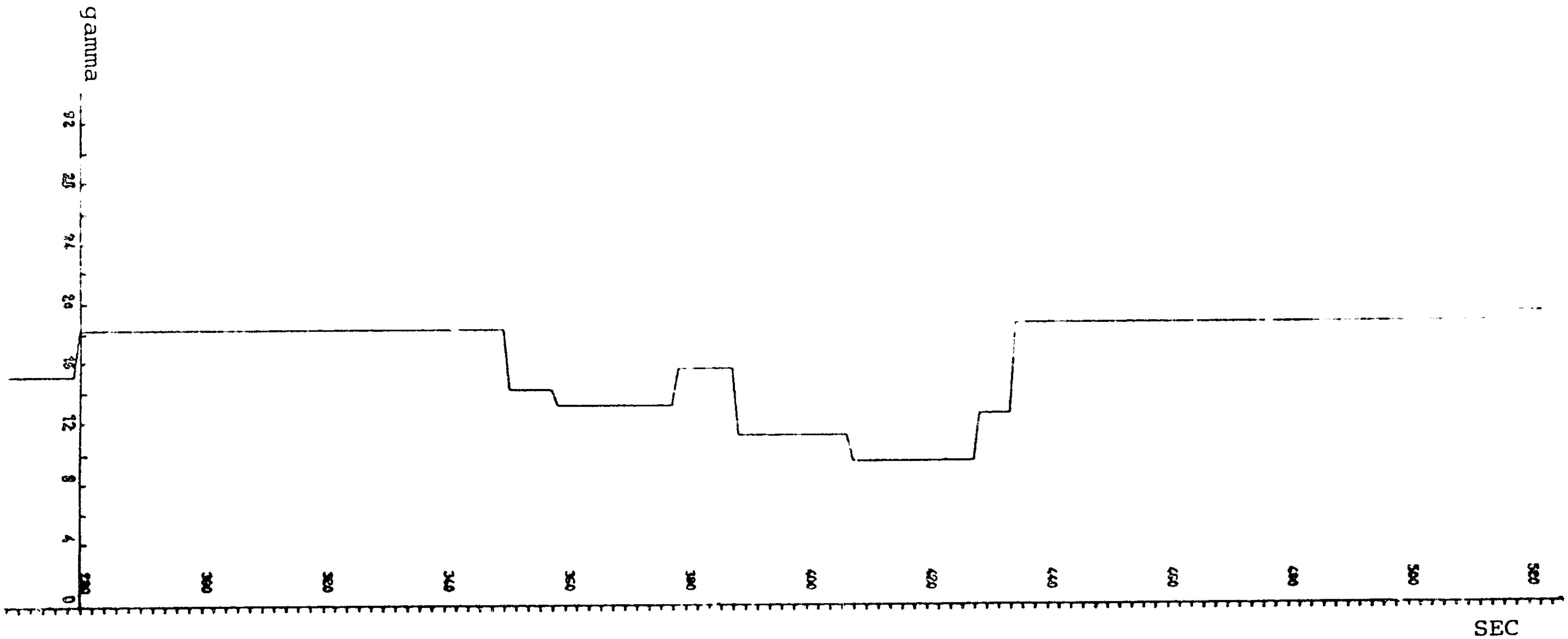

Fig. 13. Threshold 2 gamma.

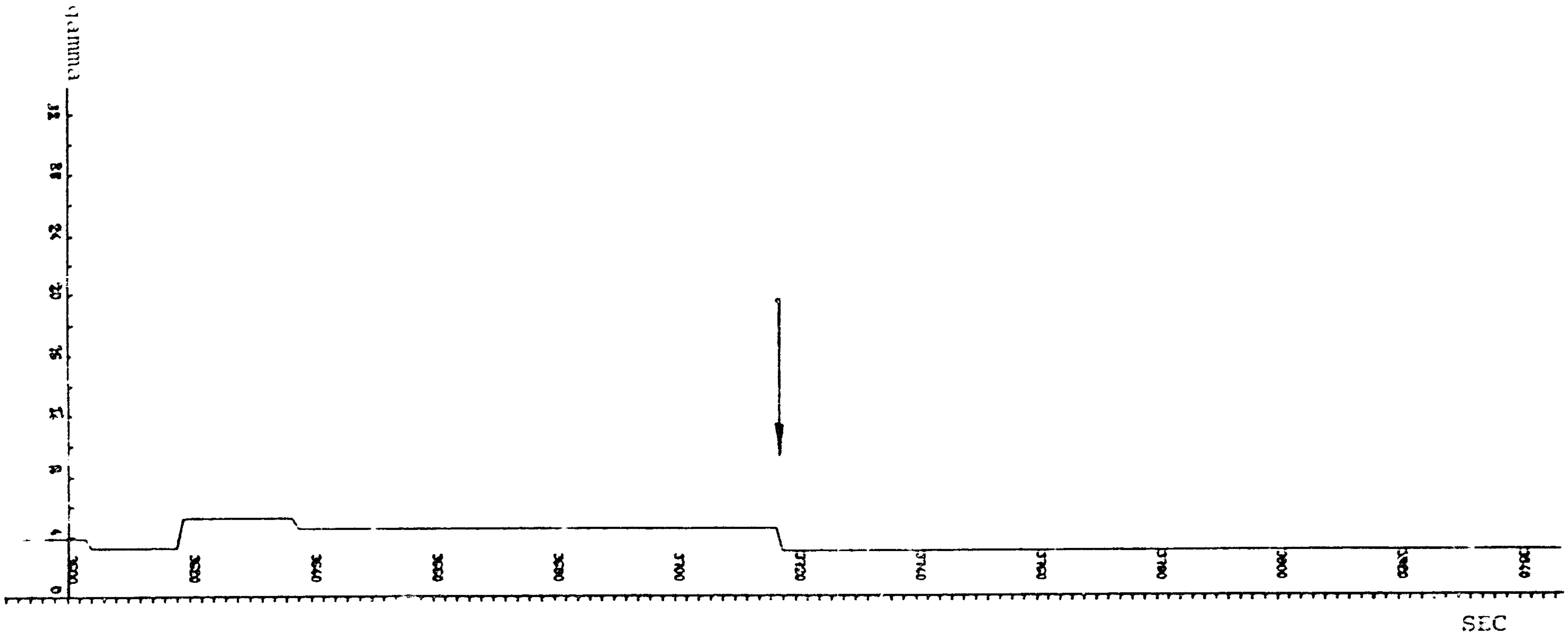

Fig. 14. Threshold 2 gamma.