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A FAMILY OF BAPTAs FOR GEO AND LEO APPLICATIONS

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ABSTRACT

The reliable function of a Solar Array Drive, a so-called Bearing And Power Transfer Assembly (BAPTA), is essential for the success of GEO and LEO missions. A failure of a BAPTA would not only jeopardize power supply but also orbit and attitude control.

For the German Communication Satellite DFS-Kopernikus, a BAPTA with some novel features was developed and qualified, including life testing. All flight models were delivered, together with an elaborate BAPTA Drive Electronics.

The modular design of this BAPTA offers a relatively easy adaptation to other specifications without losing the technological background and the experience gained.

INTRODUCTION

In the course of a proposal and selection process, TELDIX was awarded the contract for development and delivery of a BAPTA for the solar arrays of the German Communication Satellite DFS-Kopernikus in 1983. In the meantime, all flight models were delivered after an elaborate development and qualification period.

The following basic principles were used as guidelines for design and development:

1. Elimination of caging devices; instead, damping of main resonances
2. Utilization of simple suspensions; the less parts, the better
3. Preference of drive systems which require no additional suspension; additionally, simple redundancy possibilities desirable.
4. Selection of drive principles that promise straightforward control; e.g., position drives instead of torque drives.
5. Combination of sensors and drive system; at least as a redundancy means.

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6. Definition of favorable mechanical/electronic interface; mechanical "muscles," electronic intelligence.

7. Preparation of modular concept to facilitate development, production and testing.

8. Selection of materials based not only on mass and strength but also on machinability, handling precautions, surface finish, etc.

9. Utilization lubrication schemes which work essentially independent of g-levels and under air pressure and vacuum; valid testing possibilities are necessary.

10. Optimization of reliability by avoiding single point failures and using passive redundancy switch-over.

In addition, the results achieved during the development and qualification of a BAPTA with rotary transformers instead of sliprings, gimbal arrangements and momentum wheels, were introduced in the design and development process. Likewise, the experience gained with power, control, and interface electronics assisted in this development.

All this was essential, already in the proposal phase, to provide the necessary background and confidence for a successful development. In the following, after a short description of the BAPTA and its functions, the BAPTA-Mechanism (BAPTA-M) is treated in some detail. Later, possible variations of the BAPTA-M are described, which can be relatively easily obtained due to the modular design.

GENERAL DESCRIPTION

The BAPTA for the DFS-Kopernikus consists of two BAPTA-Ms (Mechanisms) and two BAPTA-Es (Electronics). Each of the BAPTA-Es is capable of driving the two BAPTA-Ms; a solar panel is linked to each of the BAPTA-Ms.

The BAPTA-Ms incorporate two direct drive swashplate motors and two zero position sensors; one motor/sensor of each BAPTA-M is connected to the NORMAL BAPTA-E, the other to the REDUNDANT BAPTA-E. The non-energized motors are disengaged by spring force. Therefore, no switching or other means for a switch-over from normal to redundant operation is necessary.

The functions of the BAPTA can be explained by reference to Figure 1. There are two angular rates provided, with a capability to rotate in both directions.

The rotational speed is controlled by quartz oscillators in a normal speed ± 360 deg/day and a fast speed ± 360 deg/25 min. The normal speed can be adjusted in the range of $\pm 5 \times 10^{-4}$ to cope with possible drifts of the quartz frequency over mission time.

The actual position is defined by a zero pick-off plus step counting by an up-down counter.

The modes of operation are the following:

- NORMAL: ± 360 deg/day, activated by TTC
- INCREMENT: ± 360 deg/25 min, activated by TTC, angular incremental range ± 307 deg preselectable in 0.075 deg steps. After rotating through the preset angular increment transition to NORMAL operation with the stored rate commences.
- SURVIVAL: 360 deg/25 min of selected NORMAL direction of rotation to zero position. Activated by AOCS; clearing is possible only via RESET (TTC).
- HOLD: One coil each of the operating swashplate motors is permanently energized. Activated by ON or RESET (TTC) or HOLD (TTC) or automatically after reaching the zero position in the survival mode.

Redundancy is provided in the following way:

Normal: Power on/signals in/out to NORMAL BAPTA-E

Redundant: Power on/signals in/out to REDUNDANT BAPTA-E.

DESCRIPTION OF THE BAPTA-M

General

The modular design of the BAPTA-M comprises three main subassemblies which will now be described in some detail:

1. Bearing Unit
2. Drive Motors with Zero Position Sensors
3. Slipring Unit.

These assemblies allow for independent manufacture and testing prior to being assembled to obtain the BAPTA-M (Fig. 2).

The mechanical interface to the solar generator is the flange on one side of the shaft. The shaft also carries, via a tube-like part, the two diaphragms with the attached gear rotors on their circumference and the rotors of the zero pick-offs.

The slipring disk is mounted on the opposite end of the shaft. The connections are routed through the hollow shaft and, equipped with connectors, provide the electrical interface to the solar generator.

The flange plate which represents the mechanical interface to the satellite structure carries the bearing unit, the motor/sensor stators, and the brush assemblies of the slipring unit.

The BAPTA-M does not require any caging device.

Bearing Unit

The geometry of the bearing unit, including the ball bearing size, corresponds largely with the one employed in the well-known momentum wheels.

The parts are manufactured from a stainless steel having identical thermal expansion as the ball bearings. This is one essential prerequisite for employing a solid preload. Thus, no variations of the preload occur in the total temperature range.

In addition, by an appropriate selection of the distance between the two bearings, the contact angle and the conformity, there are only slight changes in the preload in the presence of temperature gradients.

The ball bearings, of the size 20 mm x 42 mm x 12 mm, consist of rings made of stainless steel, TiC-coated steel balls, and plastic retainers made from a composite containing MoS_2.

Although the TiC coating of the balls would be sufficient to avoid cold welding under vacuum conditions, for the required life of several thousand rotations, the raceways and the balls have been coated with MoS_2 by a plasma process.

In the presence of a central load, the bearing unit has a load carrying capacity of $>10^4$ N in all directions. The stiffness is >1 N/μm and the tilting stiffness >10 Nm/mrad.

The nominal starting friction is on the order of 0.005 Nm.

Motors with Zero Position Sensors

The swashplate stepper motor consists of a bevel gear with 599/600 teeth, a diaphragm suspension, and 16 electromagnets mounted along the circumference of the motor stator. This special type of gear motor does not require an additional bearing suspension.

With none of the electromagnets energized, the gears are disengaged passively by the spring force of the diaphragm; the shaft of the BAPTA can be rotated freely. This is important in two ways. First, one can arrange two motors for full redundancy. Second, during vibration of the BAPTA-M while integrated into a satellite, rotational vibration component loads are generated in the shaft which load an engaged gear.

A motor is set into operation by exciting one of the electromagnets, that is, stator and rotor of the gear become engaged. The holding torque on the order of 3 Nm, offers a stiffness on the order of 1 Nm/mrad.

Sequencing of the 16 electromagnets causes the toothed gear rings to roll-off on each other. After one electrical revolution (16 steps), an advancing of one step is accomplished. The rotation is transferred to the BAPTA-M shaft via the flexible diaphragm. The sense of the rotation depends on the sequencing being either clockwise or counterclockwise.

The stepping torque depends on the overlapping in time of the excitation of two successive coils. This is due to the necessary build-up of the magnetic field over time and the time needed to perform a step. An overlapping time of about 15 msec proved to be a good compromise, taking into account the stepping frequency capability. The stepping frequency capability is 40 Hz (for the lifetest, 33.3 Hz were employed). The nominal stepsize is 0.0375 deg (9600 steps/revolution).

The gears are dry running in vacuum. The surface of the gear is ion-nitrated to ensure the specified lifetime. The number of rotations of the motor is 600 times that of the shaft; for a 10-years mission with about 3650 revolutions of the BAPTA-M, the motor has to provide 2.2×10^6 revolutions.

Since the motor is a position drive and not a torque drive, very simple and clear dynamic and control conditions are obtained.

The opto-electronic zero-position sensor, combined with an up/down counter, determines the instantaneous BAPTA-M position. This sensor has a "window" width of about 12 steps; zero with one-step-accuracy is defined by the coincidence of sensor signal and exciting of one particular coil.

For reasons of redundancy, two sensors are provided.

Slipring Unit

The slipring unit, realized in a pancake configuration, offers a particularly compact design. This feature becomes more important from a satellite's design standpoint; the available distance between the outer envelope and the central tube of the satellite becomes smaller due to the trend to longer mission time (larger fuel tanks within the central tube). Therefore, the total length of a BAPTA-M is an important selection criterion.

The main drawback of this approach, compared with a cylindrical design, is the higher friction torque which is ≤ 1 Nm.

On its front and rear sides, the slipring disc is equipped with coin silver rings that are embedded in a fiber reinforced plastic material. This approach ensures the necessary strength and also a similar thermal expansion.

Four brush assemblies are foreseen, two each on both sides of the slipring disk. Each power ring is related to four brushes while the signal rings are contacted by two brushes each. This configuration ensures both low contact resistance/noise and high reliability.

The brushes are made of sintered silver/MoS_2. The sinter mixture is such that the content of MoS_2 is nearly zero at the side where the brushes are soldered to the springs. This provides an approximately constant contact pressure. The change of the MoS_2 content over the height of the brushes is important on the one side for low wear and friction, on the other side for achieving the necessary mechanical strength of the solder connection.

Main Data of the BAPTA-M (DFS)

The main data are given in the following form:

Mass		$\leq$5.3 kg
Diameter		225 mm
Length		130 mm
Rate of rotation	normal	$\pm$15 deg/hr
	fast	$\pm$14 deg/min approx.
Step width		0.0375 deg (2.25 min)
Steps/revolution		9600
Output torque	hold	>3 Nm
	step	$\geq$0.7 Nm
	friction	$\leq$1 Nm
Zero position accuracy		1 step
Power consumption		$\leq$3.3 W
Electrical transmission		2 x 22.5 A
		8 x 4 A
		3 x 1.3 A
		12 x 0.25 A
Loads, static (qualification)		200 Nm
	or 88 Nm	+ 2000 N lateral force on interface
dynamic	20 Hz	0.013 g^2/Hz
	20 to 70 Hz	+ 6 dB
	70 to 100 Hz	0.2 g^2/Hz
	100 to 200 Hz	- 6 dB
	200 to 2000 Hz	0.05 g^2/Hz
		10.8 g RMS
Thermal vacuum		- 40°C to +60°C
		$\leq 10^{-5}$ mbar
Life		$\geq$10 years
Reliability (2 BAPTA-M + 2 BAPTA-E)		0.985 (10 years)
Power Consumption (2 BAPTA-M + 2 BAPTA-E)		$\leq$16 W

LIFETEST

A thermal vacuum lifetest at about 10^{-5} mbar was performed, after passing the vibration qualification test.

An acceleration factor of 300 was chosen, leading to a step frequency of 1/9 Hz x 300 = 33.3 Hz. At this frequency, the BAPTA-M still comes to a complete stop after performing a step; only the pauses between steps, normally a little below 9 sec, are shortened.

The qualification factors were as follows:

Operation time	>1.5 (6000 revolutions)
Load torque	>3 (0.7 Nm)
Power over sliprings	>2 (currents >1.5)
Temperature	>2 (-15^{o} to $+50^{o}$)
Temperature cycles	>3 (32)
Temperature gradient	very high ($\pm 25^{o}$C/h).

Figure 3 shows the test set-up.

The load torque was generated by a brushless dc motor (2).

The BAPTA-M (10) is mounted via a thermal insulation to the temperature controlled plate (4). This plate heats up or cools down the vertical plate shown in the figure which is in radiation contact to the circular plate (5). The circular plate is fixed to the solar generator flange. This arrangement was chosen to simulate the heating and cooling by the solar generator yokes as closely as possible.

Between the ball bearing unit rotor and stator, temperature differences of $\pm 20^{o}$C (approximately) were measured.

All temperatures, currents, and voltage drops across the sliprings were recorded continuously. A daily check of the hold, step and friction torque was performed.

After the test performance, the evaluation of the BAPTA-M resulted in the following:

1. Bearing Unit: Practically no change of the friction torque, no wear whatsoever.

2. Motors: After 3.6 x 10^{6} motor revolutions, equal to 57 x 10^{6} steps, the surface of the gears showed a polishing wear only. The motors could have been operated for a much longer time.

3. Sliprings: A very small wear on the brushes has taken place; the slipring surfaces showed "optically visible" traces only.

EVOLUTION TO A BAPTA-FAMILY

Due to the modular design, a family of BAPTAs can be defined by modification and modified mounting of the subunits. Main possibilities are the following:

- o Configuration - The basic arrangement of the motor(s) and the slipring unit is interchangeable, leading to different configurations depending on results of trade-offs or specific customer needs.
- o Power and Signal Transfer - The slipring unit is adaptable to power and slipring transfer capacity requirements, for instance, by adding to the power transfer pancake slipring a small cylindrical slipring assembly.
- o Redundancy Provisions - The motor redundancy concept can be modified from two completely separate motors to one motor using redundant windings on the motor poles, or even the same windings, connected to two redundant electronics.
- o Angular Position Measurement - Pick-offs of different types, accuracies and redundancy levels can be implemented to fulfill specific requirements.
- o Interfaces - The mechanical interfaces to the solar generator and to the satellite structure can be modified within certain limits; the electrical interfaces are fully adaptable to customer needs.
- o Drive/Interface Electronics - The BAPTA-E is adaptable to the required modes of operation, power and signal interface requirements and to various redundancy concepts.

Together with the high resolution stepper motors, for all missions, GEO, LEO and highly excentrical orbits, the speed can be adapted. For the latter, an automatic control via sun sensors on the solar generators could be beneficial.

In Figure 4, an example of a BAPTA-M design is shown with double slipring discs, located at the solar generator side, and a stepper motor with redundant windings.

CONCLUSIONS

A modular BAPTA approach permits accommodation of practically all requirements.

First flight models were delivered after rigorous qualification in the course of the DFS-Kopernikus program.

The compact, lightweight, and rigid design led to a further application in the frame of the Chinese DFH-3 program.

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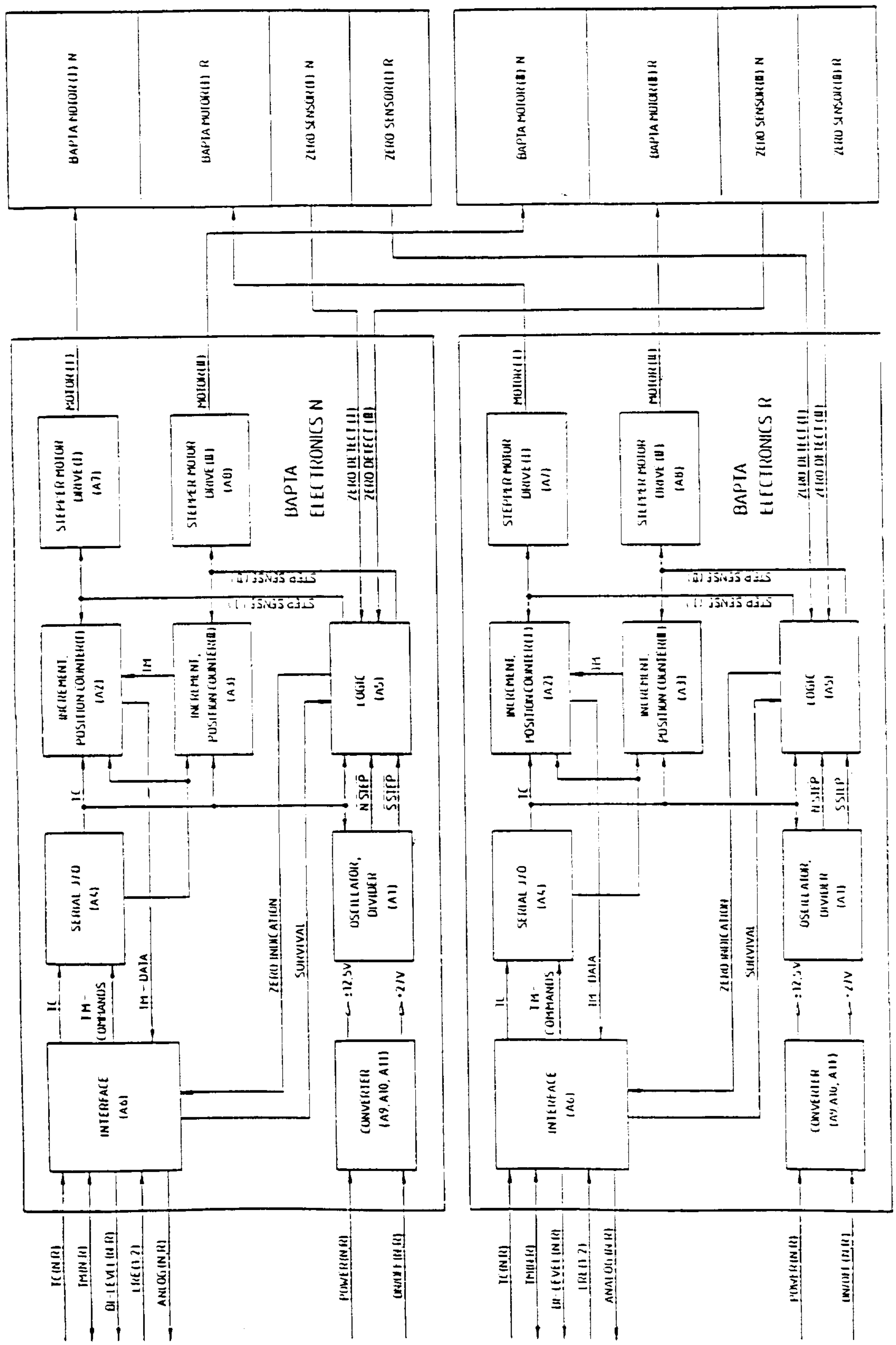


Figure 1. BAPTA block diagram.

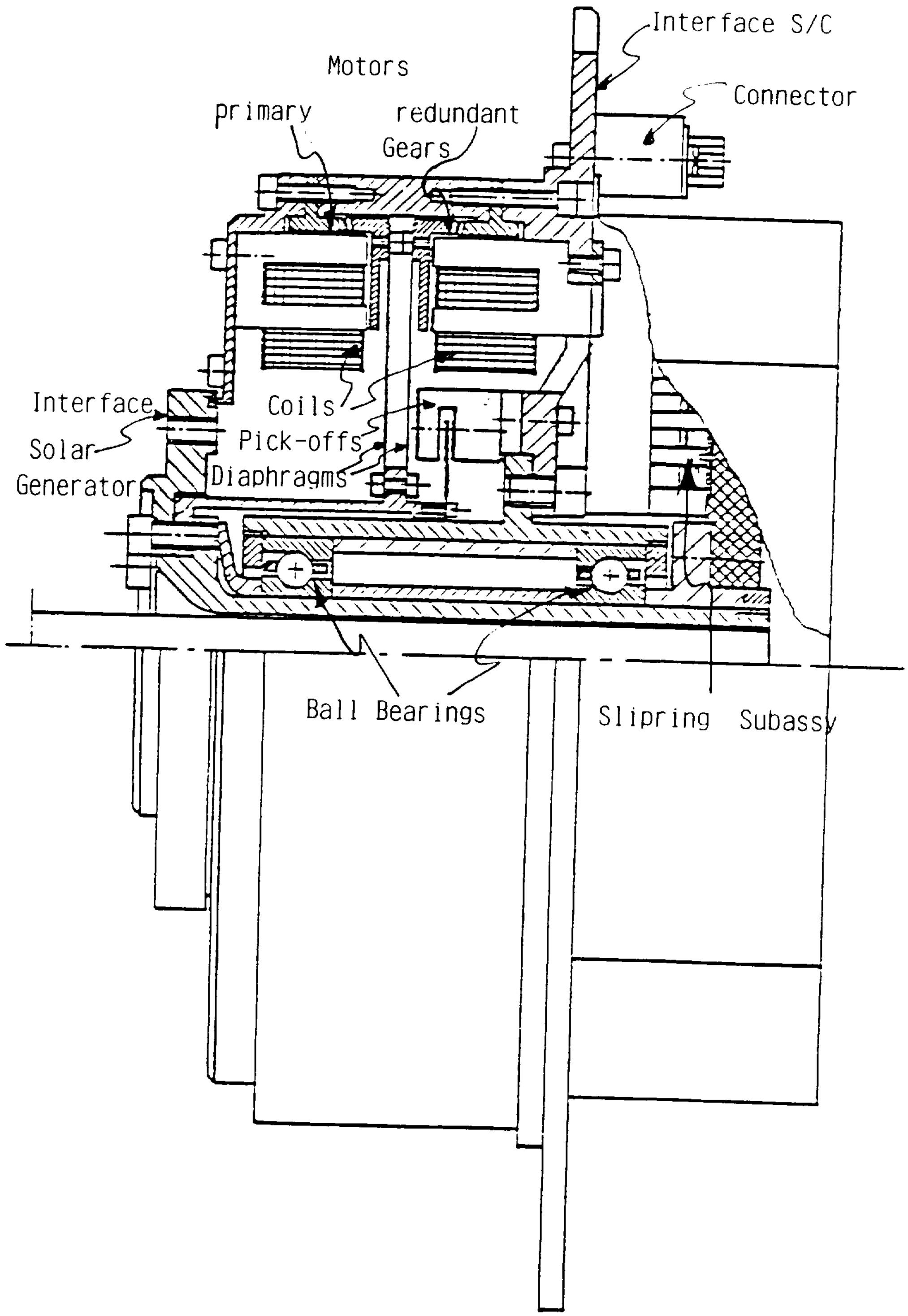
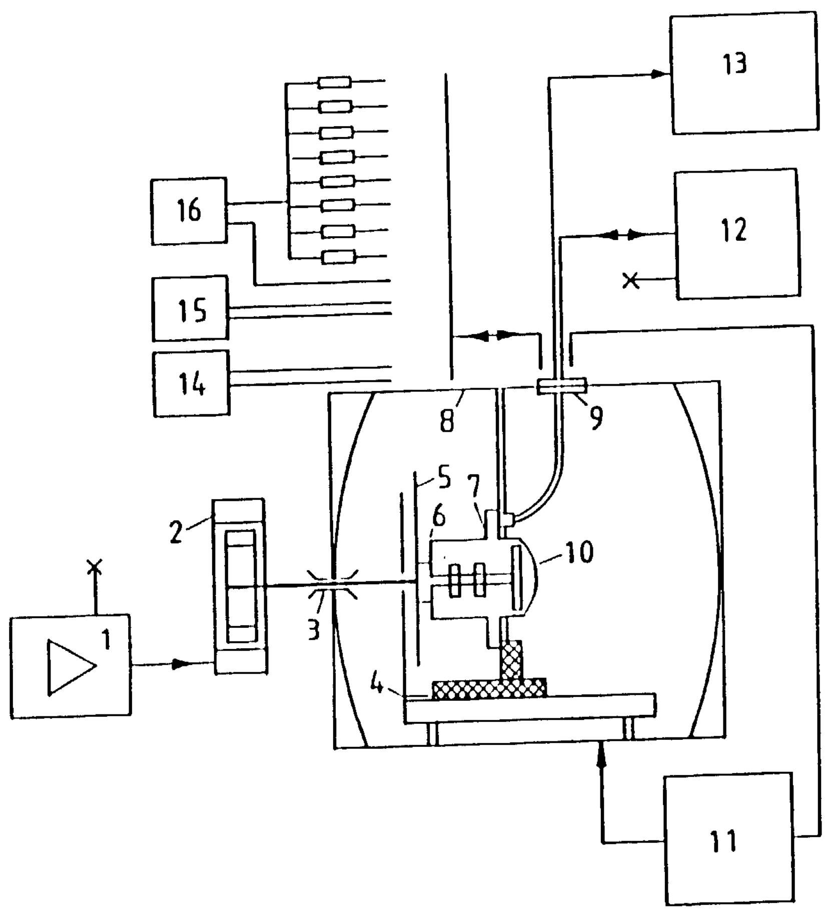


Figure 2. BAPTA-M/DFS.



1. Adjustable supply for torquer
2. Torquer
3. Rotational feed-through
4. Temp. sensor on black disk mounted to Cu-baseplate in the chamber
5. Temp. sensor on rotating black disk
6. Temp. sensor on SDA housing
7. Temp. sensor on SDA mounting flange
8. Temp. sensor for chamber
9. El. feed-throughs
10. SDA 1-0 under test
11. Temp. control unit
12. Motor drive
13. Recorder for temperatures
14. Current source 22.5 A
15. Current source 4 A
16. Current source 1.3 A

Figure 3. Lifetest on SDA.

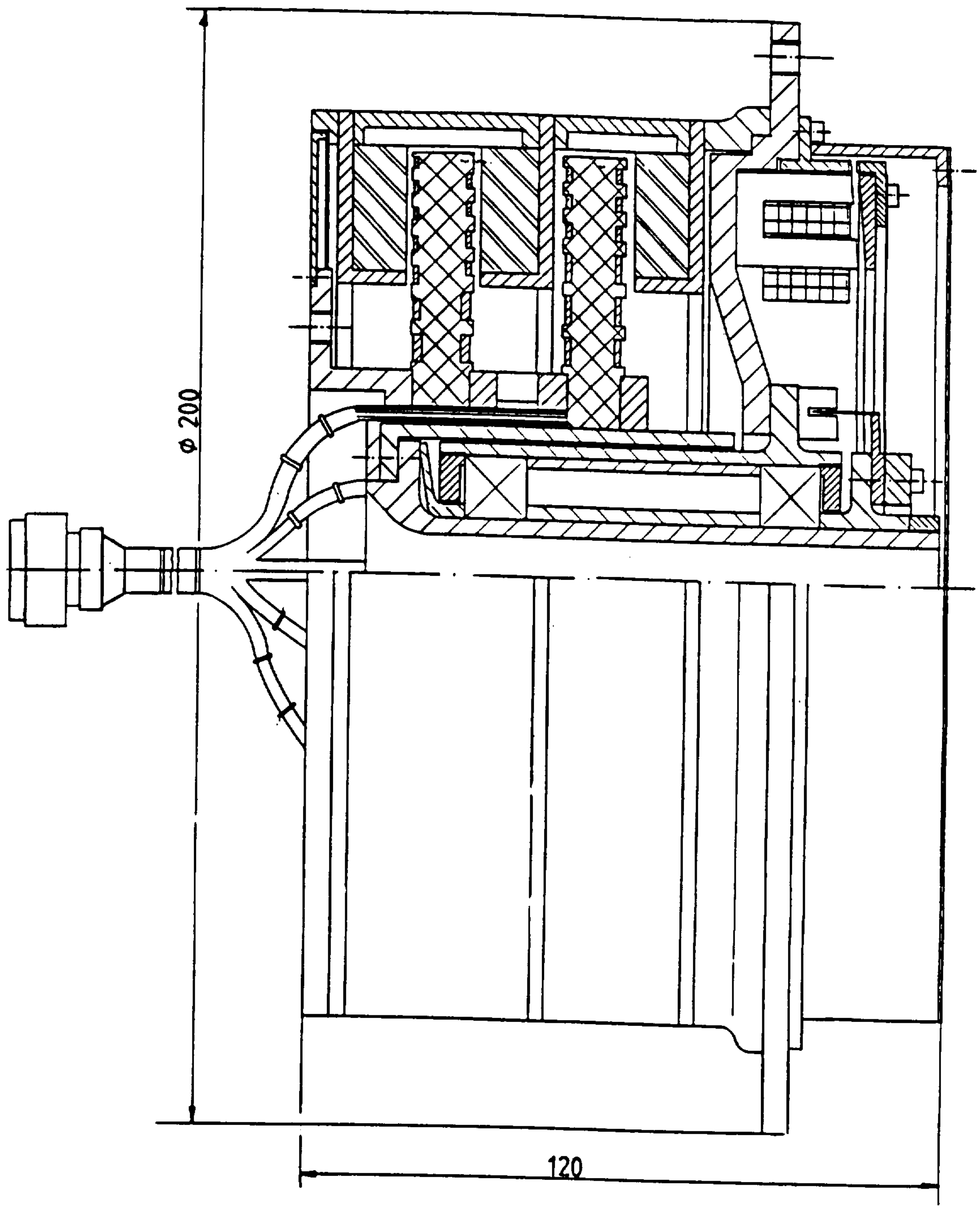


Figure 4. Example of a modified BAPTA-M.