DESIGN ASPECTS OF A SOLAR ARRAY DRIVE FOR SPOT, WITH A HIGH PLATFORM STABILITY OBJECTIVE

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ABSTRACT

SEP is developing a solar array drive mechanism (MEGS: mécanisme entraînement générateur solaire) for the SPOT platform, which is a prototype of the multimission platform developed by MATRA under CNES contract.

High-resolution cameras and other optical instruments are carried by the platform, requiring excellent platform stability in order to obtain high-quality pictures.

Therefore, a severe requirement for the MEGS is the low level of disturbing torques it may generate considering the 0.6×10^{-3} deg/sec stability required.

To reduce the mean friction torque and its fluctuations, use has been made of:

- Two angular contact, lead lubricated ball bearings having a very moderate elastic preload on orbit and completely protected against static loads and vibrations during the launch and deployment phases.
- A modular multidisc slip ring assembly of small diameter and a subsystem of electric contacts used only for pyrotechnic orders to the panels.

To reduce the torque fluctuations of the electric motor, a compensation of some defects is achieved.

Finally, the MEGS is used as a secondary actuator for damping of the solar array flexible modes.

INTRODUCTION

Multimission Platform for Earth Observation

SEP is developing a solar array drive mechanism named MEGS (mécanisme entraînement générateur solaire) for the SPOT platform. This platform is the

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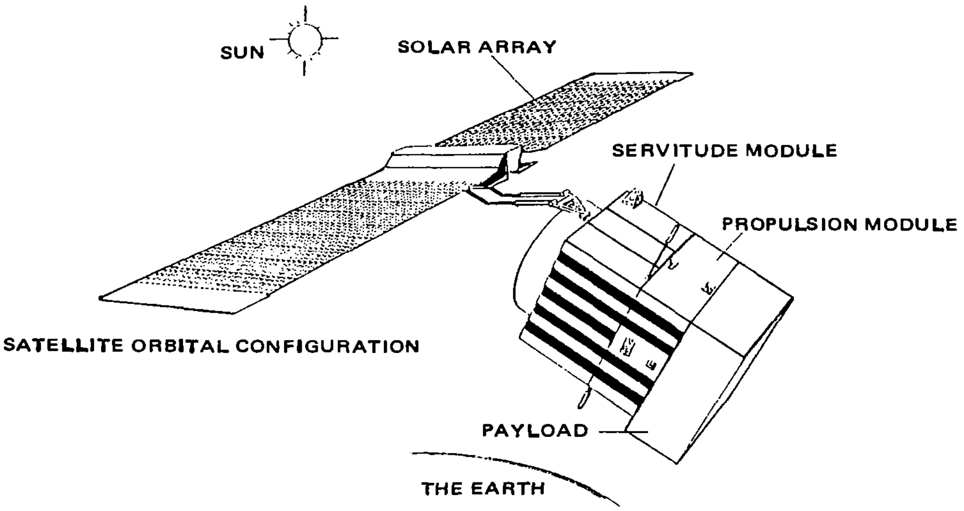
prototype of the so-called multimission platform currently being developed by MATRA under CNES contract.

The platform is, in fact, the service module, to be reused as is (or with minor modifications) on various earth observation satellites having different missions.



Picture Taking

Pictures can be taken with infrared spaceborne cameras, visible light cameras, side aperture radars, and other devices. One common need for all these instruments is a 0.15-deg/3-sigma pointing accuracy.

However, this pointing specification is not the major one to ensure good image quality; the stability of the platform and instrument is the mandatory condition to obtain high-resolution pictures.

The movement of the camera must be as small as possible during the exposure time, which is in the order of 10 sec for a full-size SPOT camera picture, thus leading to the severe rate stability specification: 0.2 to $0.6\text{X}10^{-3}$ deg/sec.

MEGS Design Aspects to Reach the Stability Required

The angular fluctuations of the platform are produced by disturbing torques resulting from the friction torque fluctuations of the ball bearings and the slip ring assembly and also from some imperfections of the electric motor.

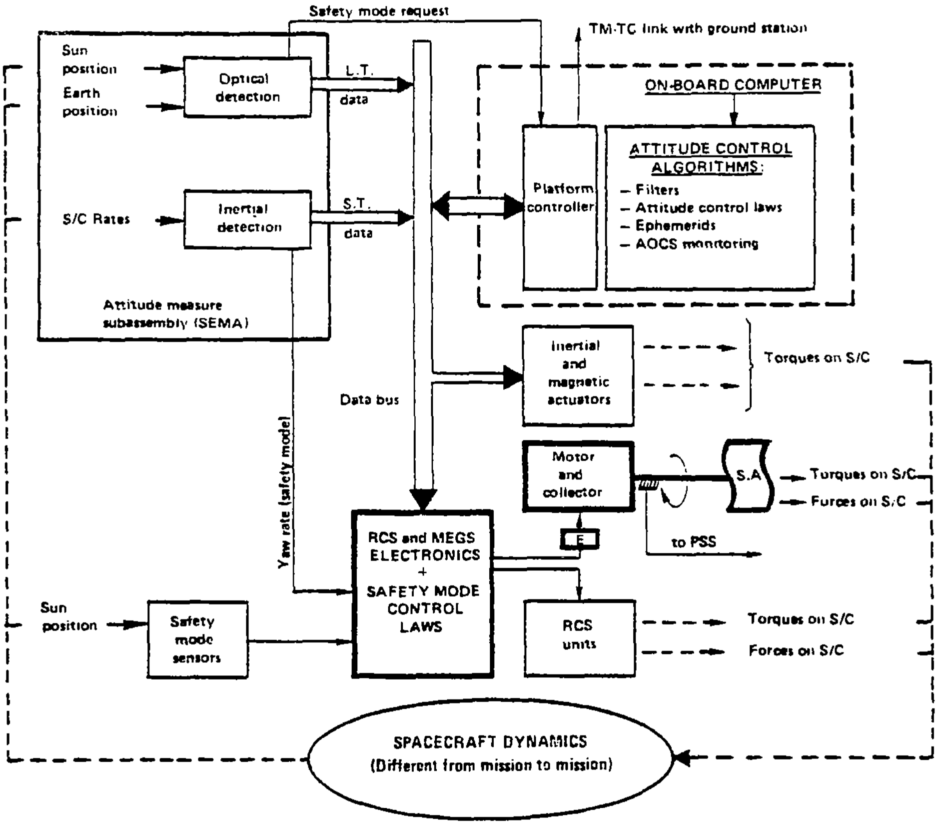
The mechanical design aspects aiming at reducing the mean friction torque, and therefore its fluctuations, are described hereafter, as well as the method of compensation of the motor imperfections. However, this is not sufficient to reach the stability requirement.

A complementary actuation of the MEGS is used also to damp the flexible modes of the solar array.

VARIOUS OPERATION MODES OF THE MEGS

The MEGS cannot be presented as an isolated mechanism. It is, indeed, intimately connected with platform stability: on one hand it is a disturbance generator, and on the other hand it is used as a secondary actuator to provide damping. It is therefore necessary to first examine how it is used.

The multimission platform AOCS (Attitude and Orbit Control System) is detailed on the block diagram below in which the various units involved in the solar array drive function are particularly shown.



MULTIMISSION AOCS: FUNCTIONAL DIAGRAM

In the various modes of operation of the AOCS, MEGS has the following functions:

- Pointing of the solar array towards the sun in the normal mode of operation with an accuracy of ±3 deg anywhere within 360 deg.
- Same function, in the safety mode of operation, with an accuracy of ±3 deg about a fixed position called the canonical position.
- Complementary actuation, in the normal mode of operation, for damping the solar array flexible modes.

In the subsystem architecture, rotation rate orders which are given to MEGS electronics either come from the AOCS onboard computer through EPRS (an AOCS electronics dedicated to actuator drive) or directly from this equipment in case of safety mode.

Typical Operation in Various Modes

Acquisition Sequence

First, the solar array is deployed; pyro orders transmit through the MEGS. Deployment status is confirmed to the onboard computer, also through the MEGS, which then authorizes the unlocking of the MEGS mechanism.

The solar array, at this time, is in the canonical position; the friction torque of the slip ring assembly and the motor holding torque maintain the arm in that position. When the satellite comes, in its orbit, to a point such that the sun direction enters the yaw-pitch plane, MEGS is automatically started by an AOCS algorithm which sends the proper PROM reading to obtain an angular rate nearly the same as the orbital rate.

Normal Mode

Long-Term Operation. Once per orbit the angular rate of MEGS will be adjusted by a special algorithm which, starting from the digital sun sensor data, compares the theoretical time to be in the canonical position with the actual one. The algorithm then deduces a new mean rate of rotation to be applied for the next orbit. The angular speed of the MEGS in real time is equal to the mean rate, plus small variations imposed by the need to control flexible modes of arm and array, as detailed hereafter.

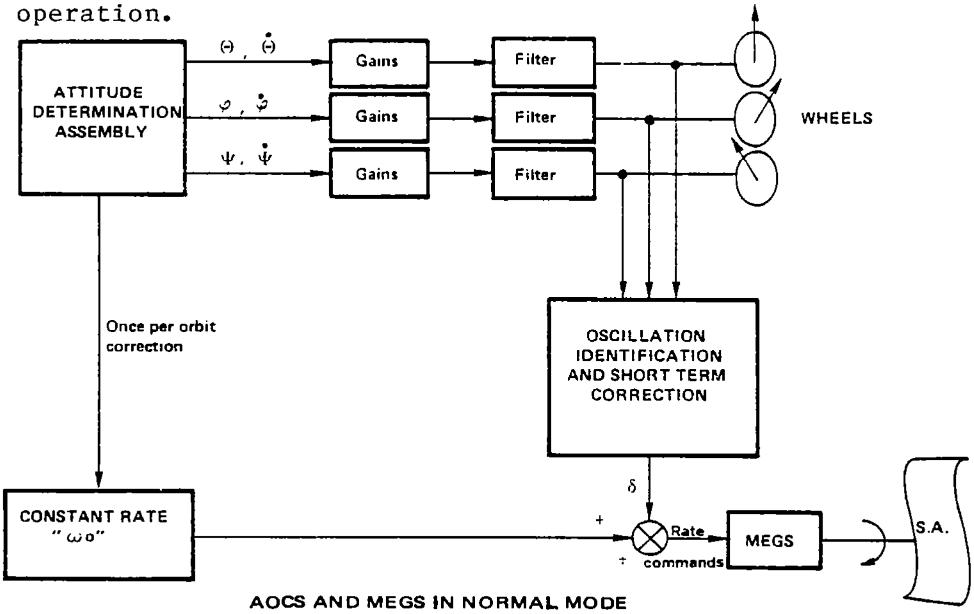
Short-Term Operation. To achieve the very good stability required, a noiseless and wide-bandwidth AOCS of about 1 Hz will be necessary to react quickly enough to tape recorder starts and to solar array drive perturbations and to keep a safe stability margin relative to solar array flexible modes:

- The MEGS generates disturbing torques at 0.1, 0.15, 0.2, and 0.4 Hz, which are harmonics 2, 3, 4, and 8, respectively, of the fundamental frequency of the stepper motor drive signals (sine and cosine) at 0.05 Hz.

- The first solar array modal frequencies are 0.11, 0.16, and 0.2 Hz. This shows a potential difficulty if the attitude control does not have sufficient phase margin at these frequencies to damp the oscillations which the drive motor will initiate in the array.
- In addition, the solar array and the electromechanical stiffness of the stepper motor will also form an oscillating system of nearly zero damping. The frequency of this last oscillator is also in the range of 0.1 to 0.2 Hz. To solve this problem, the MEGS has two possible motor stiffnesses (900 and 450 Nm/rad) which will allow selection, once in orbit, of the most favorable one with respect to the real characteristics of the array.

AOCS Control Laws for the Normal Mode of Operation. AOCS makes use of three orthogonal reaction wheels. Gains and filters are put on rate and angle outputs of the attitude detection system to refine torque commands for the wheels. This is actually sufficient to stabilize the platform down to the very low rates aimed at but does not provide damping of solar array oscillations themselves. Indeed, the MEGS excitations, at the same frequency as array modes, can lead to a situation where high wheel torques perpetually counteract high array oscillations. To cure this effect, an additional control law acts on the MEGS itself to provide damping of array oscillations. This control law, based on an in-flight identification of wheel torque oscillation frequency and phase, delivers to the MEGS delta rate commands to generate the damping torques.

The block diagram below summarizes the operation of AOCS and MEGS in the normal mode of operation.



AOCS AND MEGS IN NORMAL MODE

MEGS REQUIREMENTS

Due to its critical role in the stability of the platform, the MEGS is subject to the following requirements:

Nominal speed: 0.055 to 0.063 deg/sec

Speed stability requirement: for $0.05 \text{ Hz} \leq f \leq 0.8 \text{ Hz}$, the speed stability of the MEGS rotor, without additional inertia and in open loop, must be better than 6×10^{-3} deg/sec with the maximum values as follows:

- o Harmonic 1 (0.05 Hz) < 2%
- o Harmonic 2 (0.1 Hz) < 6%
- o Harmonic 3 (0.15 Hz) < 1%
- o Harmonic 4 (0.2 Hz) < 1%

Friction requirement: for $0.8 \text{ Hz} \leq f \leq 20 \text{ Hz}$, the torque fluctuations of bearings and slip rings must be < 0.05 Nm and mean friction torque < 0.05 Nm.

Other Constraints

The other constraints put on MEGS by AOCS are:

o Rate range: ±0.48 deg/sec

o Torque capability: ±3 Nm high level
±1.5 Nm low level

o Motor stiffness: 900 Nm/rad high-level torque
450 Nm/rad low-level torque

o Angular position reading over ±180 deg:
Accuracy between ±0.5 deg at null
±4 deg at 180 deg

o Reliability for a 2-year mission: 0.99 (approximately 10,000 revolutions)

Additionally, the loads on the MEGS rotor flange, during the launch and deployment sequence, are relatively high:

o Launching: 1,000 N in any direction
100 Nm around any axis perpendicular to rotor axis

o Deployment sequence: 100 N in any direction
±310 Nm around the deployment axis

MECHANICAL DESIGN

Ball Bearings

We have opted for a classical configuration: two angular contact ball bearings moderately preloaded by a diaphragm.

Lubrication

Our choice for lubrication is a submicron film of lead deposited on the races by an ion plating process, following the ESTL (European Space Tribology Laboratory) procedure, plus the use of a lead bronze cage. This choice was made for the following reasons:

- It is a type of lubrication which suits the very low speeds.
- The level of friction is low and independent of temperature.
- The risk of optical surface pollution is avoided.
- The endurance tests made at ESTL have shown that lead lubricated ball bearings could be operated successfully up to 10^8 revolutions. This is to be compared to the 10,000 revolutions we need!
- The behavior in air is satisfactory.
- The ESTL procedure is well defined and the experience in the field extensive.

Friction

To meet the stiffness requirements and to reduce the mean friction torque and, in a like manner, the noise and peak torques, we have adopted a moderate preload of 100 N and a relatively large angle of contact of 25 deg.

The friction torque measurements on 12 pairs of ball bearings give the following results after vacuum run-in:

Mean torque: between 1.6 and 5.9×10^{-3} Nm

Peak to peak: between 3.8 and 8.2×10^{-3} Nm

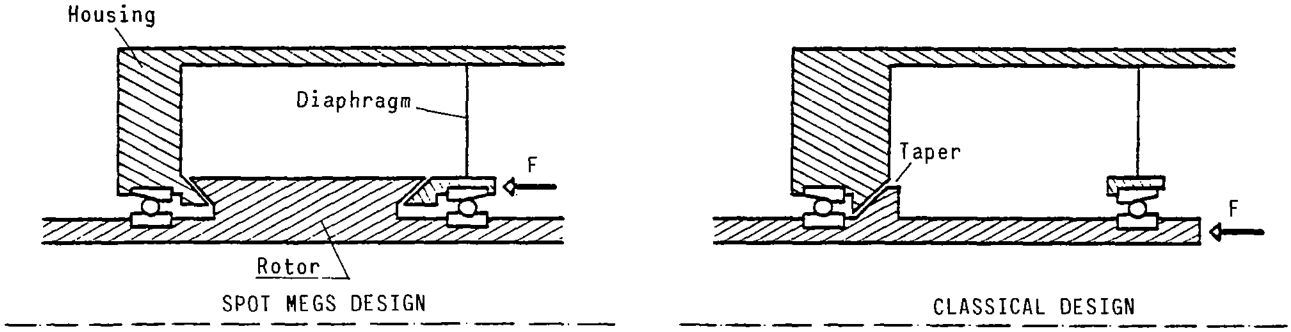
The diameter of ball bearings has been chosen as small as possible. The limit was imposed by the desirability of removing the slip ring assembly by passing the three electric connectors through a central tube of the driving mechanism, without having to remove them from the cables.

Unloading the Ball Bearings System

Several considerations led to a decision to unload completely the two angular contact ball bearings and to lock the rotor during the launch and deployment sequence: (1) the high level of forces exerted on the MEGS rotor flange, (2) lack of knowledge of the effect of vibrations on a lead film, and (3) a tight schedule without time for redesign. The solution chosen is a little more complicated than the classical one in which the front ball bearing, alone, is fully unloaded.

Figure 1 presents the two solutions. In the MEGS system, the force to unload the ball bearings is applied to the external ring of ball bearing set no 2. When this force goes beyond the preload value produced by the diaphragm, the deformation increases, causing contact between the first pair of rotor-stator tapers and resulting in dismounting of ball bearing set no. 2. Then as the force is further increased, the rotor goes forward further, causing contact between the second pair of rotor-stator tapers and producing the dismounting of ball bearing set no. 1.

Thus, the rotor is entirely sustained and locked by the tapers, and the ball bearings do not experience any static load or vibrations.



SPOT MEGS DESIGN

CLASSICAL DESIGN

Figure 1. Schemes of Unloading Ball Bearings System

Figure 2 presents the system in the two states: during launch and in orbit.

A redundant pyrotechnic wire cutter is used to release the system.

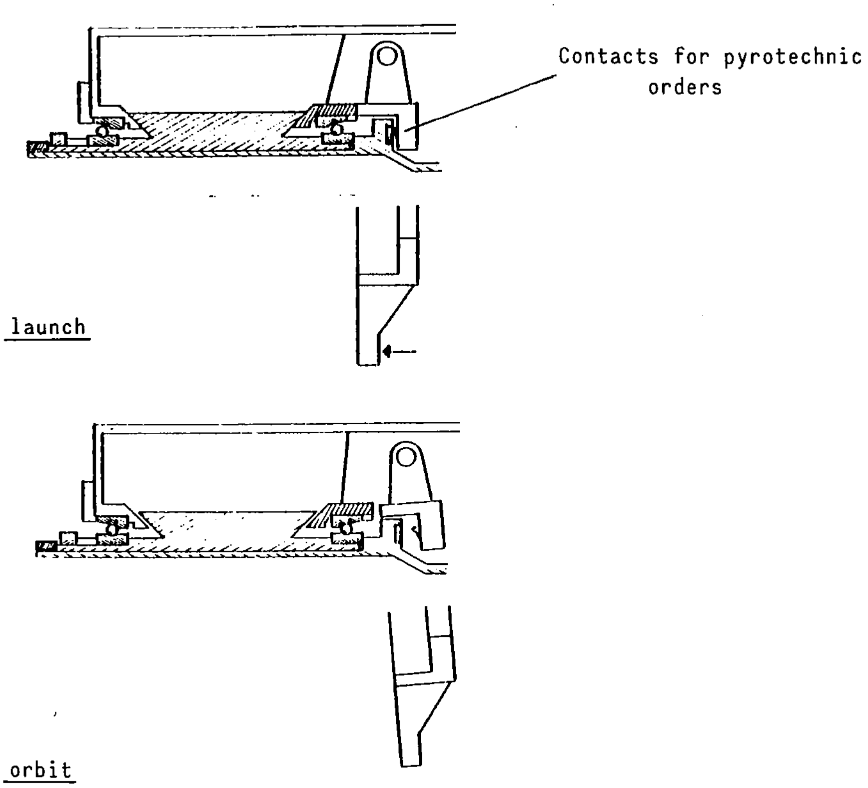


Figure 2. Scheme of the Unload System in the Two States

Slip Ring Assembly

The slip ring assembly is developed by MECANEX in Geneva, under SEP supervision.

Materials

The choice of materials is classical:

- o Rings in coin silver
- o Brushes in sintered composite of 82.5% silver, 15% molybdenum disulphide, and 2.5% copper

Design

To minimize the friction torque, we used small-diameter slip ring discs. The disc allows certain positioning defects of brushes which are not tolerated with cylindrical rings (see Figure 3).

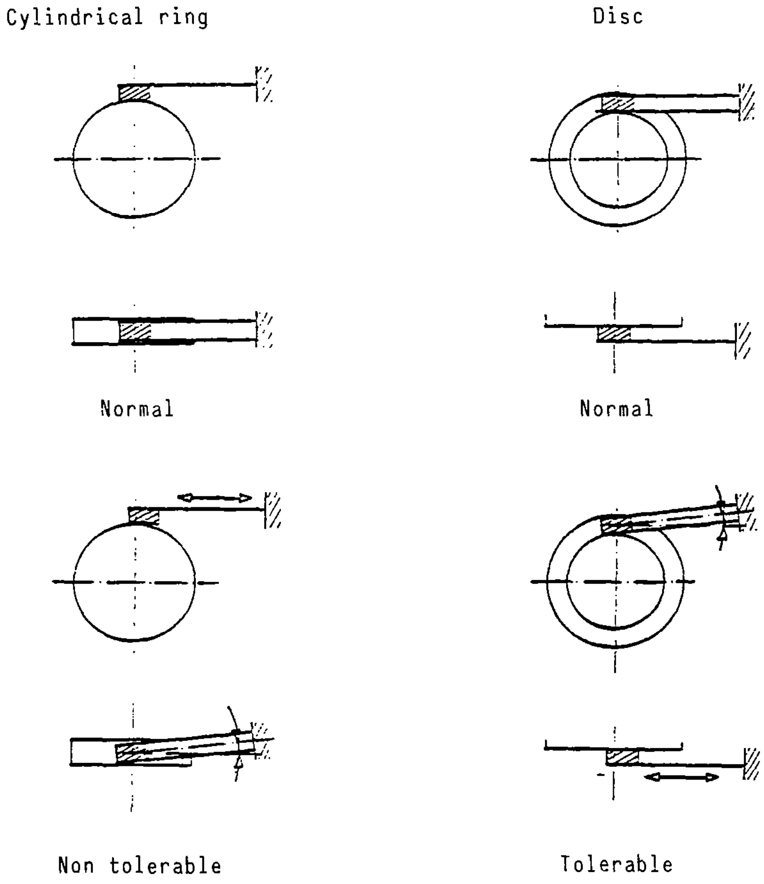


Figure 3. Advantages of Disc Over Cylindrical Ring

The MEGS slip ring assembly is modular. This presents numerous advantages:

- Lower risks of manufacturing
- Lower costs because of the facility of molding the simplified modular elements
- Possibility of adaptation to different missions

In addition, the design allows for easily separating the slip ring assembly from the driving mechanism. A central tube, which is a part of the slip ring assembly and through which passes the electric cable, goes through the driving unit. It is possible to separate the two subassemblies without disassembling the electrical connectors.

The slip ring disc assembly of MECANEX consists of 11 discs having a power and a signal slip ring on each side. The mean diameter of the power slip rings is 31 mm, and the mean diameter of the signal slip rings is 41 mm.

A subassembly of 10 electrical contacts allows the transmission of the pyrotechnic orders to the solar array. These contacts are broken by the motion of the release lever after array deployment. Thus, a saving of 10 slip rings and their friction has been achieved.

Friction

The mean friction torque measured in the air is 0.25 Nm. The tests in vacuum have not yet been conducted.

COMPENSATION OF THE SAGEM ELECTRIC MOTOR

The SAGEM electric motor is a 1,200-step-per-revolution stepper motor operated in synchronous mode. Although its manufacturing is very carefully done, it presents some defects, the compensation of which is hearafter presented.

First, when the motor, without any load, is energized by two sine and cosine voltages, its angular speed fluctuates around the average speed proportional to the voltage frequency (0.05 Hz). The speed fluctuation of the rotor corresponds to that of the magnetic field, since the load torque is very small (friction torque of ball bearings only).

Second, the motor stiffness is not constant over a voltage period. This appears, for a constant torque load, as a variable lag angle of the rotor referred to the magnetic field during one period and, consequently, a speed fluctuation during the same time.

The aim of the compensation is to reduce to a minimum these fluctuations in order to reduce the disturbances on the platform.

First Method

In this method, the compensation is obtained in two stages: compensation at no load and compensation at fixed load torque.

Compensation at No Load

This consists of energizing the motor by two shaped voltages from the sine and cosine basic voltages so that the amplitude of the magnetic field is constant but its angular speed is opposed to the observed defects.

Experience shows that the distortion observed on one period (which corresponds to four steps) and in which the fourth harmonic is preponderant is approximately the same whatever the period.

The corrections achieved on one period are registered on floppy disc before being PROM programmed. Figure 4 shows the method.

If the motor was perfect, the rotation angle θ versus time would be a straight line Δ. But an actual curve $\theta = f(t)$ is plotted. It can be seen, for instance, that at t_1, the actual position θ_R is smaller than the theoretical position θ_T. To obtain an actual position θ_T at t_1, the two voltage levels applied at this moment must differ from A_1 and A_2 and must be equal to B_1 and B_2, which correspond to θ_T on the actual curve $\theta = f(t)$. The corrections are achieved at 64 points of the period. The results are shown on Figure 5.

Compensation at Fixed Load Torque

The first compensation having been achieved, a load torque approximately equal to the mean friction torque is applied to the rotor.

The second compensation consists of modifying the magnetic field intensity, without changing its direction, in order to modify the stiffness.

Figure 6 shows the method. At t_1, the theoretical angle of lag $\theta'_T - \theta_T$ of the rotor with regard to the position θ_T at no load is not achieved. Actually, it is $\theta_R - \theta_T$.

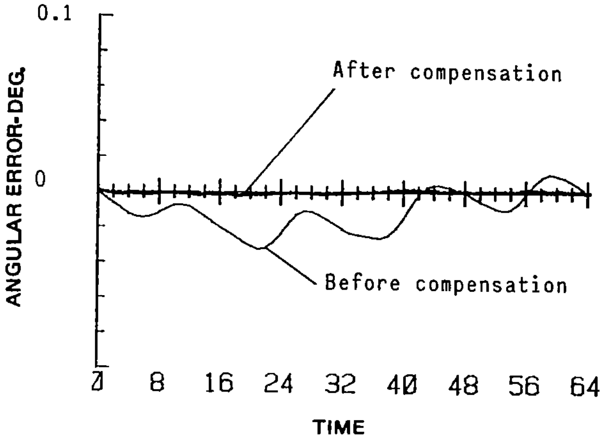
The compensation consists of modifying both voltages at t_1, in the same ratio

$$\frac{\theta_R - \theta_T}{\theta'_T - \theta_T}$$

This does not modify the direction of the magnetic field but, in the case shown, increases its intensity and therefore the motor stiffness, resulting in an actual position θ_T.

Only the first stage of this mode of compensation has been achieved with success. The second stage will be achieved in January 1982.

Angular error



Speed variation

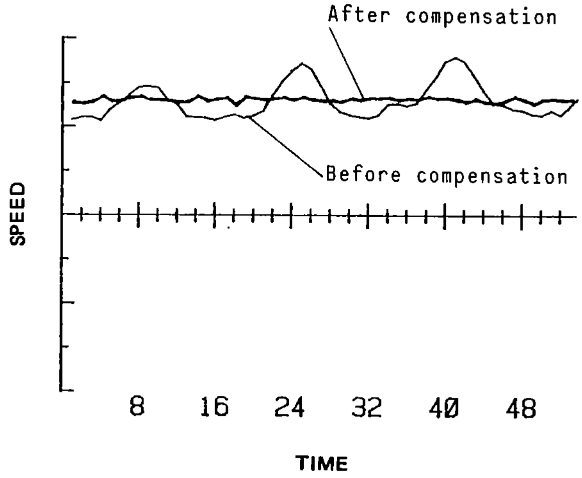


Figure 4. Compensation of the Motor at No Load

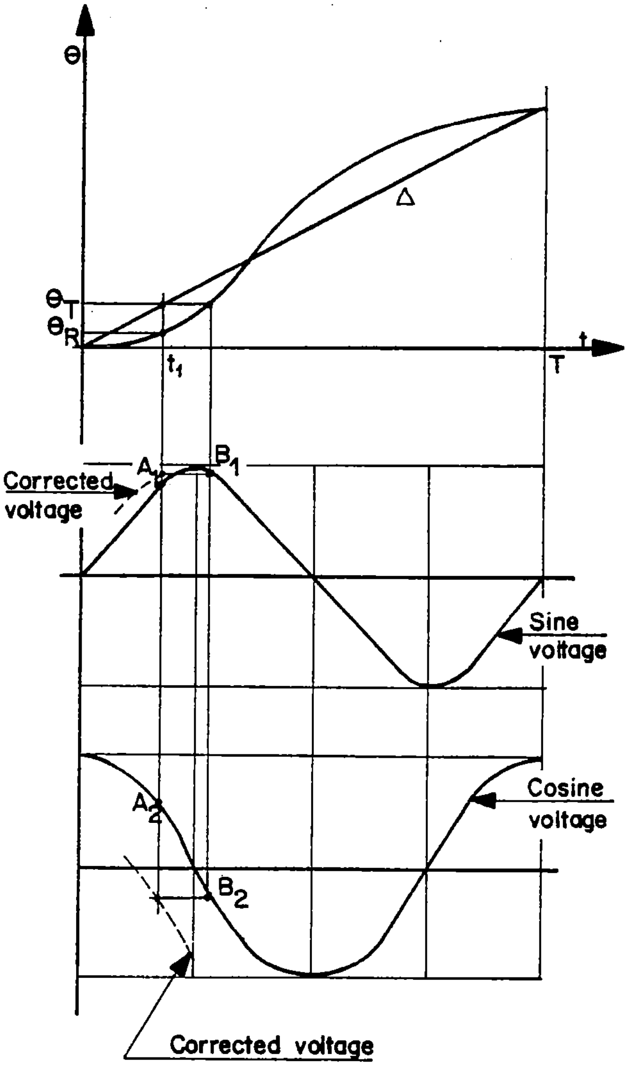


Figure 5. Compensated Motor at No Load

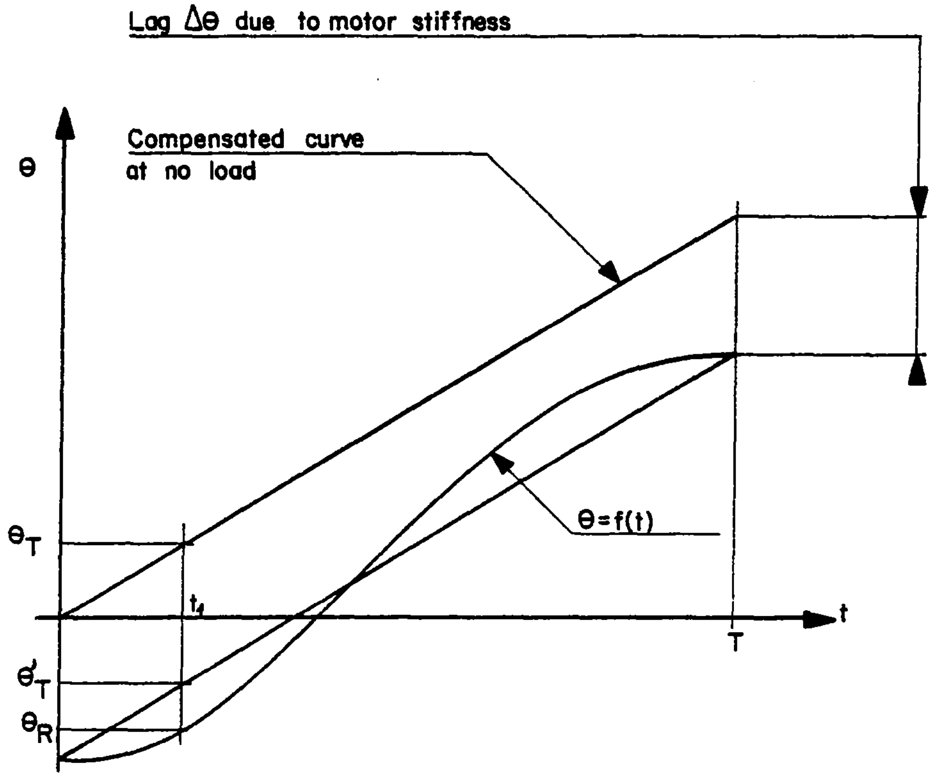


Figure 6. Compensation of the Motor for a Constant Load

Second Method

This method is accomplished in the same manner as that of the first stage of the first method, but with a load torque of 0.25 Nm.

Experience has shown that the fourth harmonic level, which was about 15%, was reduced to:

1.09% at no load

1.13% for a 0.5-Nm load torque

The choice between the two methods will be decided after testing is completed.

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When Mr. Cabillic first joined SEP in 1971, he was responsible for the servo-actuators as well as other equipment on the Ariane. Since 1979, he has been responsible for the electromechanisms in the Space Division. Prior to his joining SEP, he was with the Laboratoire de Recherche Balistique et Aérodynamique as head of the department concerned with servomechanisms, servo-actuators, equipment for launchers, inertial equipment, and testing facilities. Mr. Cabillic graduated from Ecole Nationale Supérieure de Mécanique de Precision.

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