10. A NEW APPROACH TO LONG-LIFE NONCONTACTING ELECTROMECHANICAL DEVICES

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INTRODUCTION

Development efforts have been underway for a number of years at the Goddard Space Flight Center to improve the life and reliability of electromechanical devices intended for spaceflight applications. This work has progressed to the point where it appears feasible to think in terms of completely noncontacting devices for many applications. These devices are based upon the following technical approaches:

(a) magnetic suspension of moving elements

(b) direct drive to eliminate gear reducers

(c) brushless drive motors

(d) noncontacting position encoders

(e) rotary transformers for transfer of power and signals

The purpose of this paper is to discuss the advantages and penalties of this noncontacting philosophy. Following papers will survey the present state of the required component technology and describe an actual hardware application.

WHY NONCONTACTING SYSTEMS?

The prime motivation for elimination of all physical contact is the hazard of operating rolling or sliding members in the space environment. There is at present - and none appears on the horizon - no ideal space lubricant. Fluid lubricants are subject to one or more of the following limitations: poor temperature viscosity characteristic, poor lubricity, outgassing and contamination, evaporation, creep, shear instability, and radiation damage. Dry films are life limited and tend to be non-self-healing. Sliding electrical contacts have similar lubrication problems, complicated by the requirement of maintaining electrical resistance within some very narrow range of acceptable values.

The next point is that sooner or later the mechanical bearing, brush, or gear will wear out, and it is impossible to predict when this will occur. Many devices are to be designed for lifetimes of several years, or longer, and the problem of testing to establish life expectancy is very formidable. Once the big step is taken to eliminate all contact, all mechanical random and wear out failure modes are eliminated and life expectancy becomes a function of control electronics reliability.

Additional advantages, some of which are not immediately evident, are gained including the following:

(a) Life Independent of Speed:

The life of most conventional bearings is inversely proportional to some power of rotational speed. Noncontact support removes this limitation, which can be exploited to advantage in momentum storage and certain other applications.

(b) Wide Temperature Range:

Noncontact systems can be designed with generous clearances and, being free of lubrication limitations, can be operated at very high and very low temperatures. There are prospects for improved efficiency of magnetic bearings at low operating temperature.

(c) Noise Reduction and Isolation:

Due to irregularities in balls and raceways, even the best conventional bearings generate objectionable noise spread over a broad range of frequencies. Magnetic bearings are expected to markedly reduce the overall vibration level and restrict the disturbance to predictable discrete frequencies.

(d) Torque Perturbations and Breakaway Stiction:

In servo controlled rate and position systems, the breakaway stiction of bearings and brushes and the dynamic perturbations of shaft torque that they produce are major problems. Ultimate pointing accuracy or speed control is frequently limited by this variable. The breakaway friction for a noncontacting magnetically suspended device is extremely low (less than .25 of the best antifriction mechanical bearing). It is, for all practical purposes, a constant plus a small rate dependent term. This is clearly an ideal characteristic for the servo system designer.

(e) Backlash and Gear Train Windup:

The noncontact approach implies direct drive and the elimination of all forms of gears, belts and traction drives. In addition to eliminating the friction and wear of such devices, backlash and windup are eliminated. These factors, like stiction, are serious limitations to accuracy and bandwidth of high performance servo systems.

LIMITATIONS OF NONCONTACTING SYSTEMS

Looking at the other side of the coin, one must consider the penalties imposed by the noncontact philosophy:

(a) Cost:

Magnetic bearings will be much more expensive. Conventional antifriction bearings, even where exotic space lubricants are applied, cost perhaps 5K dollars per set. Magnetic bearings will start at 10 times this value. Brushless dc motors are also more expensive than ac or bruf' type motors, but this margin is narrowing and should not represent a major consideration in future systems.

(b) Weight:

With certain exceptions (such as optimized momentum storage systems), there will be a weight penalty incurred with magnetic suspension. In many applications, this will be critical. In the era of the shuttle, however, it is expected that weight constraints will be drastically relaxed.

(c) Power:

Magnetic bearings require power to support shaft loads. In zero gravity, or where the load is essentially static, power consumption can be minimal (2 - 8 watts). Dynamically varying loads require about .3 watt per pound support power. In higher speed applications, support power is at least partially compensated by reduced rotational losses in the noncontact bearing.

(d) Stiffness and Load Capacity:

Magnetic bearings are presently limited in their effective stiffness (deflection under load) characteristics and their load capacity. Stiffness also deteriorates with increasing frequency under dynamic load conditions.

(e) Torque vs. Weight and Power:

Since speed reduction is eliminated, direct drive systems generally suffer a weight and power penalty under high torque and inertia load conditions.

(f) Impact on Structural Design:

At the present state of development, special consideration must be given in the structural design of the device to assure compatibility with the magnetic bearing servo dynamics. One should assure that housing and shaft natural frequencies are high relative to the servo resonant frequency. It is also necessary that bearing servo compensation be optimized for each application. These are not monumental problems, but they do inhibit the ready interchangeability of magnetic bearing designs in various applications.

SOME REPRESENTATIVE APPLICATIONS

Some potential spaceflight applications of the noncontacting approach are:

(a) Momentum Storage:

A following paper discusses the application to an attitude stabilization momentum wheel. Additional application to control moment gyroscopes, bias momentum wheels and, possibly, reaction wheels is predicted. Although performance of these components with conventional bearings has been remarkably good, there have recently been failures that would indicate dependable operation beyond 3 years is questionable. Figure 1 illustrates a rim supported and driven momentum wheel which is under development. This configuration has a very high momentum to weight ratio, particularly at rim speeds approaching one mach. The desirability of noncontacting support at this velocity is self-evident. If, and when, flywheels are applied for energy storage, magnetic suspension will be a strong candidate.

(b) Scanning Radiometer:

Figure 2 shows the conceptual application of noncontacting principles to an image plane scanning radiometer. A requirement here is for precise rate control and stability of the spin axis of the scanning wheel. The low torque perturbation of the magnetic bearings assures attainment of the first goal. Achieving the desired positional accuracy (± 2 seconds of arc) with magnetic bearings has not yet been demonstrated. The closed loop nature of the device is a favorable factor, but improvements in present position sensing techniques will be required.

(c) Mechanically Despun Antenna:

Figure 3 is a conceptual arrangement of a despun antenna, with all physical contact eliminated. Rotational rates range from 15 to 100 rpm, requiring a low speed, low destabilizing force motor. Transfer of radiofrequency (RF) energy is from the stationary feed to the despun reflector. Alternatively, a noncontact choke type rotary joint could be employed.

CONCLUDING REMARKS

Brushless dc motors are finding increasing application in space and it is likely that they will be the predominant type within the next few years. Likewise, with the advent of the light emitting diode, noncontacting encoders are gradually replacing sliding contact types. The direct drive concept has proved its merit and is now the preferred approach for tape recorders and low to moderate torque instrument drives. The final step in this evolution is the magnetic bearing, which now appears feasible for several applications. Where it can be applied in a totally noncontacting system, life and reliability will be a function of the electronic controls, where redundancy, derating, and quality assurance approaches can be applied to virtually assure the desired lifetime and failure rate.

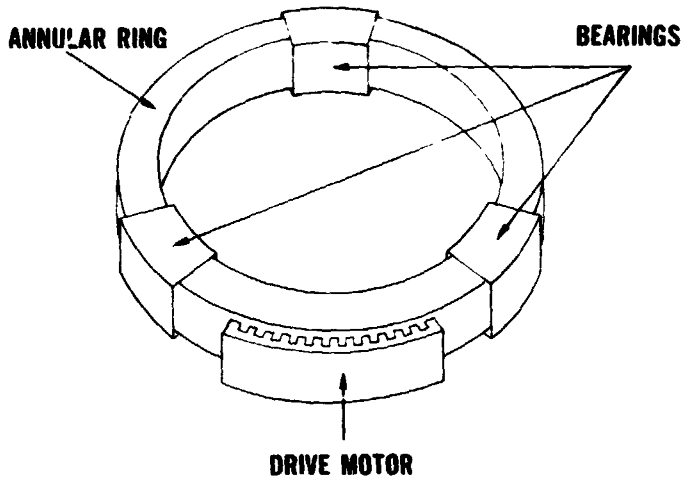

Figure 1.- Annular momentum control device.

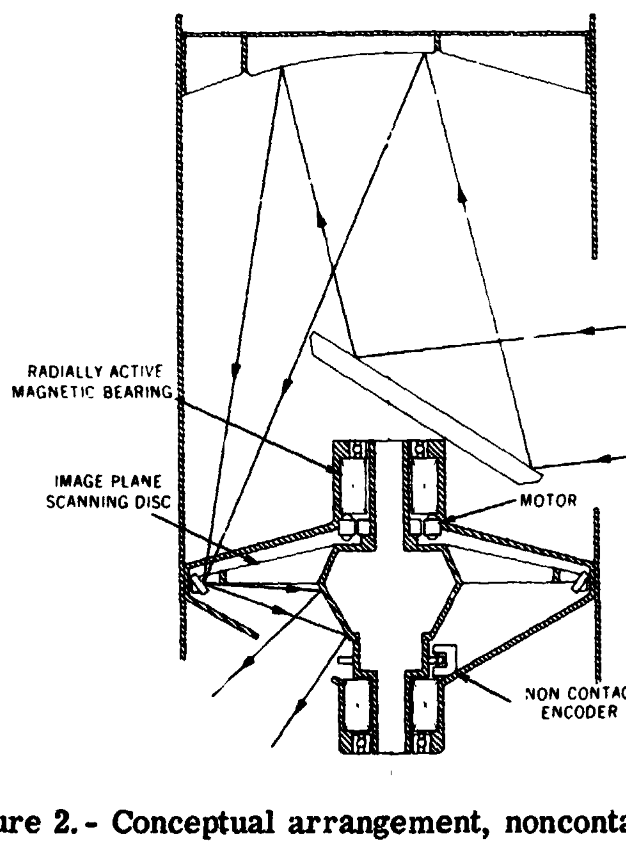

Figure 2.- Conceptual arrangement, noncontacting image plane scanner.

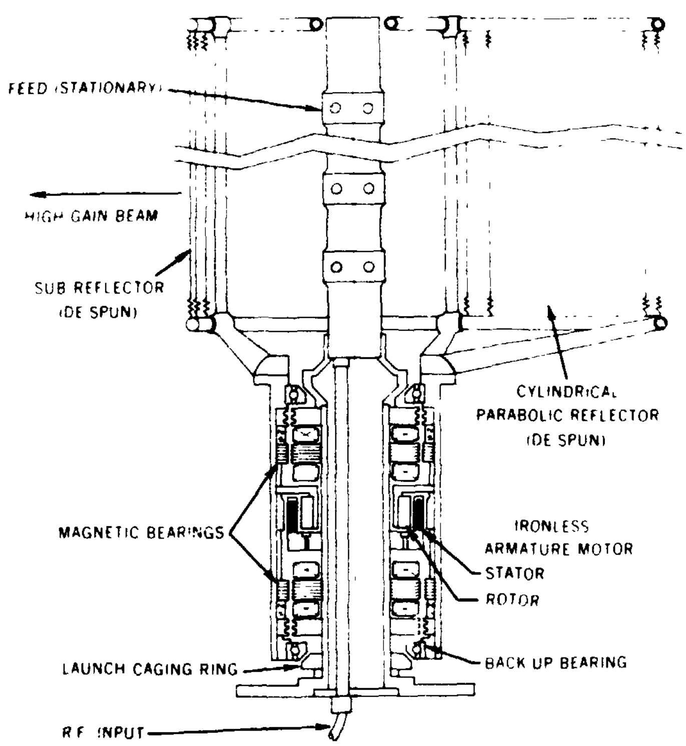

Figure 3.- Conceptual design, noncontacting despun antenna.