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DOCKING SYSTEM OF ANDROGYNOUS AND PERIPHERAL TYPE

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ABSTRACT

Soviet and American space engineers have proceeded with creating compatible means for closing and docking spacecraft. It was decided to make a new advanced docking system of a peripheral and androgynous type. Because of a more complex design of the new-type docking mechanism, a number of technical problems arose. To a great extent, the solution of these problems depends on a chosen concept of the docking mechanism. The report deals with the docking system concept accepted by the Soviet engineers as the basis for further development. The description and structural arrangement of the docking system as a whole, its basic assemblies, and a kinematic scheme of the docking mechanism using a system of differentials are given. It should be noted that the experience that was gained from the development of previous docking systems was used to create a new type of docking system. The main problems to be solved in the course of designing and developing the advanced system are noted.

INTRODUCTION

Having developed the proper docking systems and having realized the docking of spacecraft, Soviet and American space engineers proceeded with the creation of compatible docking systems which, if necessary, allow the spacecraft of both countries to dock with each other. The specialists came to an agreement that the design of the systems may be different and only such a minimum number of elements and parameters should be unitized that will ensure the docking of spacecraft. It is natural that, on the one hand, the designers of each country try to use the experience acquired in developing the docking means for previous projects and, on the other hand, they wish to improve these means. Moreover, they try to develop such equipment and structures of spacecraft that would meet tomorrow's tasks and could serve as the basis for solving more complex and multipurpose space-program problems than the present ones.

The docking system for joining spacecraft is a complex multifunctional assembly of the spacecraft. While developing such a system, many technical problems such as dynamics, kinematics, strength, thermal control, and so forth must be solved. The docking system for the Soyuz spacecraft and a further modification for the Soyuz-Salyut

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space system is designed according to the principle that is called "probe-drogue." The docking systems for the Gemini and Apollo spacecraft are designed in accordance with the same principle. However, the specialists of both countries came to a conclusion that, unfortunately, the docking system having a probe and a drogue suffers from at least two substantial shortcomings. First, the probe and the drogue occupy the central part of the system; however, in most manned spacecraft it is expedient to use it for creating an intravehicular transfer tunnel. Second, when both parts of the system to be docked are alike and can operate both actively and passively, the ensurance of androgyny presents some difficulties.

Therefore, proceeding to the design of a new docking system, the specialists of both countries agreed to develop a system of a radically new peripheral and androgynous type. The docking mechanism of this system performing the main functions of joining spacecraft is located around the periphery of the docking ring. By means of thorough analysis is shown that, in solving many problems connected with the creation of the peripheral-type system, the experience and technology of the probe-droge-type docking system may be used successfully. This report deals with the description of the concept of the docking system of an androgynous and peripheral type that allows the solution of a number of technical problems of principle inherent in designs of this type.

DOCKING SYSTEM CONCEPT

It is expedient to assume that each part of the docking system to be installed upon the spacecraft to dock and further referred to as a docking assembly consists of two main units: the docking ring with elements located on it (structural latches, electrical and hydraulic connectors, actuators, transducers, and so forth) and the docking mechanism, which, for the design considered, is located around the periphery of the docking ring. Although these two main units may be connected closely to each other, their functions are substantially different in essence and in the sequence of performance.

The general view of the active and passive docking assemblies is shown in figure 1, and the front view of these assemblies is shown in figure 2. As was stated, the docking assembly is designed to be androgynous. The identity of the active and passive assemblies is achieved by the use of the assemblies that have a common axis of opposite symmetry that coincides upon docking (axis I-III in figure 2). All of the mating elements of both the docking ring and the docking mechanism to be joined upon docking are placed symmetrically about this axis. The docking mechanism consists of a guide ring (located on six moving rods), a drive, and a system of kinematic links between the rods. The docking mechanism accomplishes impact attenuation, coupling, alinement and pulling of the spacecraft until contact. The docking ring houses the interface seal, structural latches, actuators, pushers, transducers, and other elements.

Before docking, the active spacecraft extends the guide ring into the extreme forward position. The ring of the passive spacecraft is placed into the extreme retracted position. Such a preparation would permit the accomplishment of all docking operations using the mechanisms of the active spacecraft only.

Structural joining of the docking rings that ensure sealing is accomplished, for this design, by means of a system of structural latches after the interfaces come into contact with the help of the docking mechanism.

The latches exert a preload that ensures the compression of the seal and the integrity of the interface under internal pressure and under all external loads that occur during flight in a docked mode. The desirability of a secondary link through the use of structural latches results from two factors. First, it permits the use of a low-power drive for latches having a small stroke (several millimeters) and a large force (approximately 20×10^3 kilograms (20 tons)) at a comparatively small power of the docking-mechanism drive, which has a large stroke (several hundreds of millimeters) and significantly less force. Second, it allows an increase in the number of shackling points, which is necessary to provide for the sealing and integrity of the interface. The primary docking mechanism link in a joint mission can be used as a redundant safety link.

Sets of mechanisms, on board both spacecraft, capable of performing all docking and undocking operations must ensure higher reliability. In case of failure, the active-spacecraft docking mechanism can be turned into the passive mechanism by retracting the ring into the extreme rear position. In case of a complete failure, the possibility for its jettisoning and the use of reserve guides is provided (fig. 3).

In performing docking by the active spacecraft, some operations of docking and undocking can be accomplished by means of mechanisms of the passive spacecraft. The pyrotechnics can be used as a redundant means for undocking the spacecraft.

The docking ring shown in figure 2 has electrical and hydraulic connectors that are similar to those which were successfully used in the Salyut and Soyuz docking systems. These elements are connected at the final phase of pulling the spacecraft together by the docking mechanism. The electrical connectors in the interface permit, if necessary, the control of mechanisms (as well as other systems of the second spacecraft) and data exchange between the crews before the transfer hatches are opened.

The docking assemblies are self-contained units and can be mounted on various spacecraft, which significantly facilitates design, manufacture, development, and testing. This factor is particularly important in creating compatible designs.

The docking assemblies are equipped with a system of transducers, the signals of which carry data on performing docking and undocking operations to the pilot panel, through a telemetry system to the ground, and into the docking-system control device to provide the possibility for automatic performance of main operations. The automatic control and commutation device is mounted on the docking assembly to facilitate testing of the system as a whole.

DOCKING MECHANISM

The "double ring and cone" principle employed in the docking mechanism is a novel concept. To attain attenuation in all degrees of freedom relative to the movement of spacecraft, the ring should possess six degrees of freedom in relation to the body.

The ring is mounted on six rods that are gimbaled both to the body and to the ring. In order to ensure the necessary freedom for the ring, all rods must have the capability of translational movement independent of each other. The rods should be provided with attenuators and a drive for further pulling of the spacecraft. In order to ensure alinement and pulling of the spacecraft without misalinement, the movement of all rods is synchronized.

The concept that was developed includes one drive for moving the ring, one attenuator for absorbing most of the energy, and a kinematic link between the rods through the system of differentials (fig. 4). Actually, the rods are screws equipped with ball-screw assemblies. Nuts of these assemblies are connected with each other and with the drive through five differentials that provide five degrees of freedom for the ring because of changes in the rod lengths (that is, to move along the lateral axes and rotate relative to three main axes). The drive has a self-adjusting clutch. When the clutch is slipping, the ring can move along the longitudinal axis in the sixth degree of freedom.

Thus, the clutch that has a stable slippage moment owing to a regulator provides the spacecraft-impact attenuation in the longitudinal direction and, at the same time, it is the drive-safety device that limits the force of pulling the spacecraft. The slippage moments in both directions may be different.

To return the ring to a mid position after its deflection, each differential is fitted with a spring-loaded mechanism that has a high value of preload in both directions. Such a value provides the precise, stable return of the ring to the mid position and holds it in this position.

In the general case, the spacecraft are misalined just prior to the first contact. At impact, the active-spacecraft ring moves (because of guides) until it matches with the ring of the passive spacecraft. Simultaneously, the energy of the spacecraft relative movement in the lateral direction and the relative rotation is absorbed by the torsion of the springs. At the moment of matching the rings, three capture latches of the active-spacecraft ring are coupled with the latches on the body of the passive spacecraft.

After accomplishing the coupling and after absorbing the main portion of the impact energy of the longitudinal movement, the spacecraft are alined by the spring-loaded mechanisms of differentials, which return the ring to the mid position when the friction clutch is slipping. For intensive damping of the spacecraft relative oscillations after coupling and for better energy absorption during the ring deflections at the first impact, electromechanical dampers (ref. 1) producing a force that is in proportion to the movement velocity of the rods, are connected to nuts of each rod. While the ring moves with the help of the drive, its speed can be within several millimeters per second (the impact velocity usually is equal to several hundred millimeters per second) and the dampers do not add an appreciable load on the drive.

Each differential has a mid-position transducer that corresponds to the mid position of the ring (along the corresponding coordinate). The transducers can indicate the initial extended and retracted positions of the ring without misalinement (in conjunction with a signal from the drive stop contacts), the completion of alinement, and the due course of pulling the spacecraft. If misalinements occur, signals from the transducers can be used in the docking-system control device and for transmitting data to the pilot panel and through the telemetry system to the ground for analysis.

To eliminate the ring misalinements in the course of pulling the spacecraft, the differentials may be fitted with controlled locks that prevent the differentials from mismatching. The necessity for such locks may become evident in the course of more detailed development and experimentation.

One of the most important problems in designing the docking mechanism of a peripheral type is the choice of possible ring deflections because this range determines primarily rod lengths, longitudinal dimensions of the assembly as a whole, and assembly as a whole, and assembly weight. To facilitate the coupling, it is advisable that the range of the ring deflections be equal to the corresponding maximum errors in the relative position of the spacecraft upon the initial contact and that the forces be minimum but, in this case, the docking-mechanism dimensions increase. The second limit case occurs when impact forces do not exceed maximum allowable limits, and the range of ring deflections is small and is determined by the magnitude of the stroke, during which maximum possible energy of impact is absorbed. Apparently, a rational solution of the problem is somewhere between these two limit cases. To solve the problem, it is necessary to conduct theoretical and experimental investigations of coupling dynamics.

DOCKING RING

The body of the docking assembly with the docking ring is the primary structure which houses all other elements and units including the docking mechanism. The forward part of the docking ring contains a system of structural latches. This design uses the system of latches that was developed for the Soyuz docking system and it meets the androgynous principle. The system consists of eight latches that distribute the force to 16 points equally spaced around the docking ring. The system is actuated by one electric drive, has a closed cable loop between the latches, and has pyrotechnics for redundant undocking. The latch system functioned well during development and flight tests. Electrical and hydraulic connectors and spring-loaded pushers mounted on the docking-ring interface satisfy the androgynous principle as well.

To provide the guiding-pin operation with allowance made for tolerances or when the dimensions change because of temperature drops and strain, one of two pins or one of two sockets of the assemblies to be docked must be movable in the lateral direction. The androgyny of the assemblies is preserved by a lock on the guiding pin that is used for locking the pin of the active spacecraft.

Two types of rubber gaskets were developed to be used as an interface seal. They are similar for both assemblies and form two redundant seal rings. The first type consists of two half-rings of different diameters (fig. 2) connected by comparatively wide radial parts. When the docking rings contact, the half-rings come into contact with the metallic surface of the docking ring interface and the radial parts touch each other. The second type consists of two concentric rings that come into contact with similar rings of the second spacecraft upon sealing.

The docking ring must have special devices that would provide for the functioning of a system for pressurizing the interspace between the hatches of the docked spacecraft, as well as systems for pressurization check and pressure release inside the interspace before undocking. When there are two gaskets, the space between them, which is of a very small volume, can be used to make a rough but very quick check.

The structure of the assemblies with hatches is shown in figure 1; a drive for opening it and a drive for pressurization are present. In addition, the provision is made for manual pressurization and hatch opening, both from inside and outside.

USE OF THE EXPERIENCE ACQUIRED

In developing the docking-ring housing and the mechanisms, most parts of the Soyuz-Salyut docking system units are used. Some units of docking systems developed earlier (such as ball-screw pairs, electromechanical brakes, and the self-regulating brake) also were used in designing the docking mechanism. More detailed analysis, however, makes it possible to draw a closer analogy between the docking mechanism that has the system of differentials and the mechanism of the probe-drogue type used in the Soyuz spacecraft.

In spite of a very complex system of attenuation, alinement, and pulling that results from the necessity for moving the guide ring in six degrees of freedom, the principle of designing the systems is the same. First, the same kinematic elements are used for both attenuation and pulling, the friction brake being used both for absorbing the impact energy along the longitudinal axis and as the drive safety element. Second, lateral and angular viscoelastic, attenuators are used that return the system to its initial alined position after damping. The advantages of such a system were mentioned in reference 2.

The analysis of the dynamics of the spacecraft impact through an attenuating system of the peripheral type also reveals that the impact process of this mechanism has some features in common with features of the probe-drogue-type system. The methods of computations developed earlier and some conclusions made on the basis of this analysis also can be used. However, docking dynamics is a specific subject and cannot be considered in a limited report.

According to one of conclusions derived from the dynamic analysis, it is expedient to create a substantial difference in forces produced by the longitudinal attenuator and the lateral viscoelastic attenuators, which is ensured by the friction brake. In this case, the advantage of the differential kinematic link between rods becomes evident. Translational movement of the active-assembly ring occurs only after complete coupling with the passive one, and the quantity of this movement is small, even at maximum closing velocity. This quality of the attenuating system simplifies the choice of the required range of possible ring deflections and, finally, reduces the assembly dimensions.

CONCLUDING REMARKS

The present description of the concept of a peripheral and androgynous type docking system, which the U.S.S.R. specialists took as a starting point for further work, is based on the results received in the initial phase of its development. Much design, development, calculational, and experimental work should be carried out to create such a system. However, preliminary design and subsequent work make it possible to say with sufficient degree of reliability that it is possible to create a docking system meeting the requirements and recommendations given in technical specifications that were determined by the Soviet specialists together with their American colleagues. Joint efforts and mutual information exchange will promote the advance of the spacecraft technology.

REFERENCES

1. Syromyatnikov, V.S.: Docking-Mechanism Attenuator with Electromechanical Damper. Paper presented at 5th Aerospace Mechanisms Symposium (Greenbelt, Md.). NASA SP-282, 1971.

2. Syromyatnikov, V.S.: Docking Devices for Soyuz-Type Spacecraft. Paper presented at 6th Aerospace Mechanisms Symposium (Moffett Field, Calif.). NASA TM X-2557, 1972.

DISCUSSION

J. H. Parks:

It is beyond the scope of your comments, but could you comment on any problems to date or any anticipated problems related to such things as dimensional-tolerance specifications and so forth? This question is in consideration of the fact that the Soviets use the metric system and our working drawings still tend to involve the inch-foot-pound system.

C. C. Johnson (for Syromyatnikov):

At one of our first meetings with the Soviet engineers, we jointly agreed to use the International System of Units in all interfacing situations. We had some misgivings but, in practice, there has been little inconvenience and no confusion. However, neither the Soviets nor we feel comfortable with the newton; we both continue to express force in weight units.

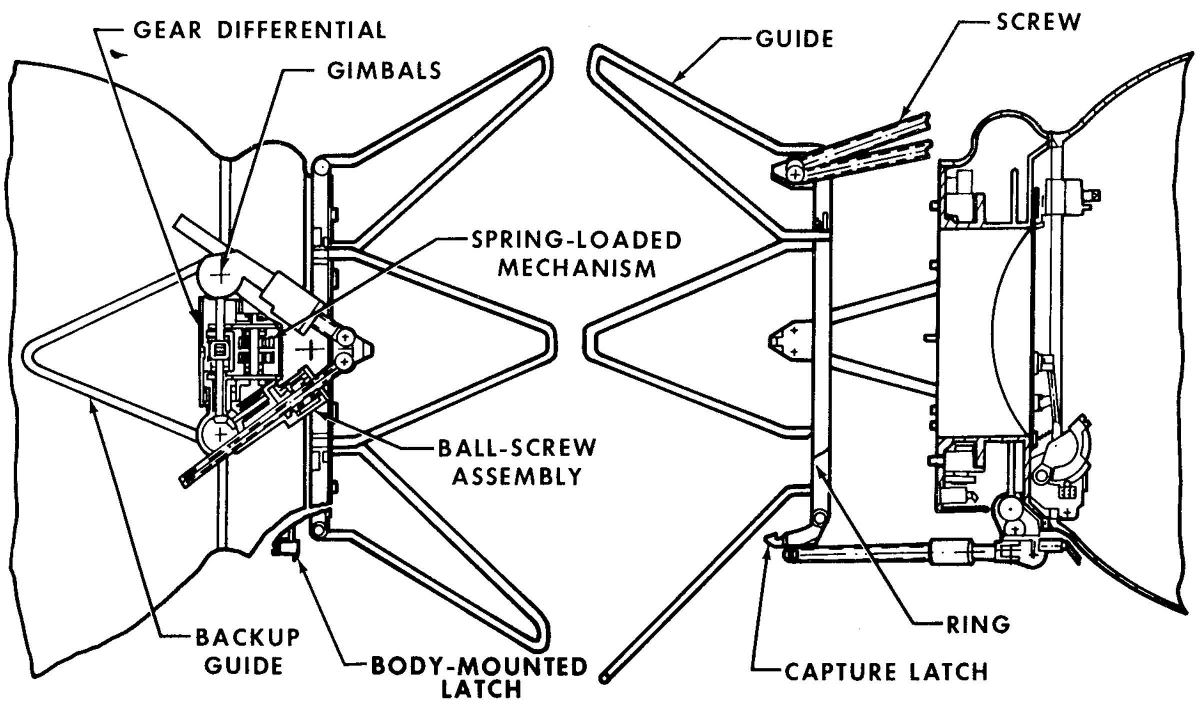

Figure 1. - General view of the active and passive docking assemblies.

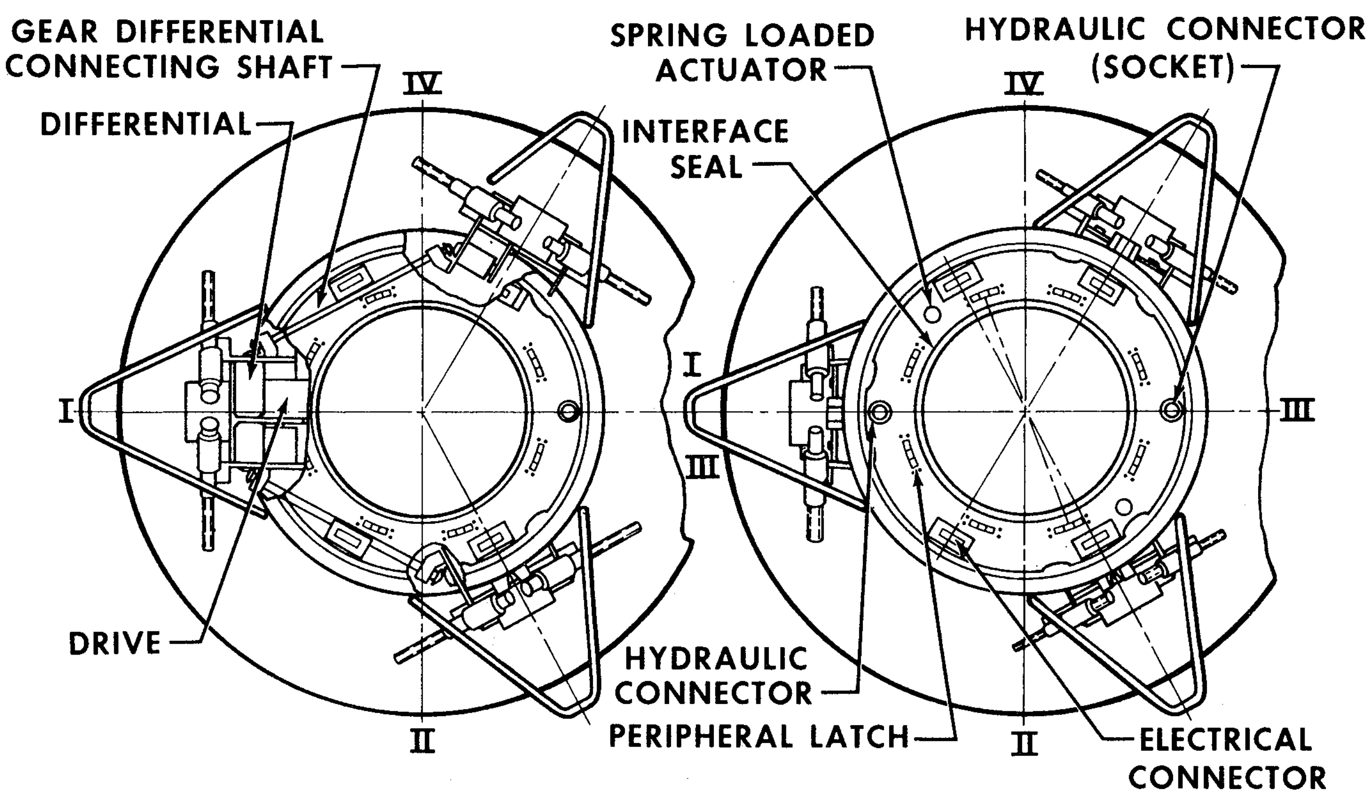

Figure 2. - Front view of the active and passive docking assemblies.

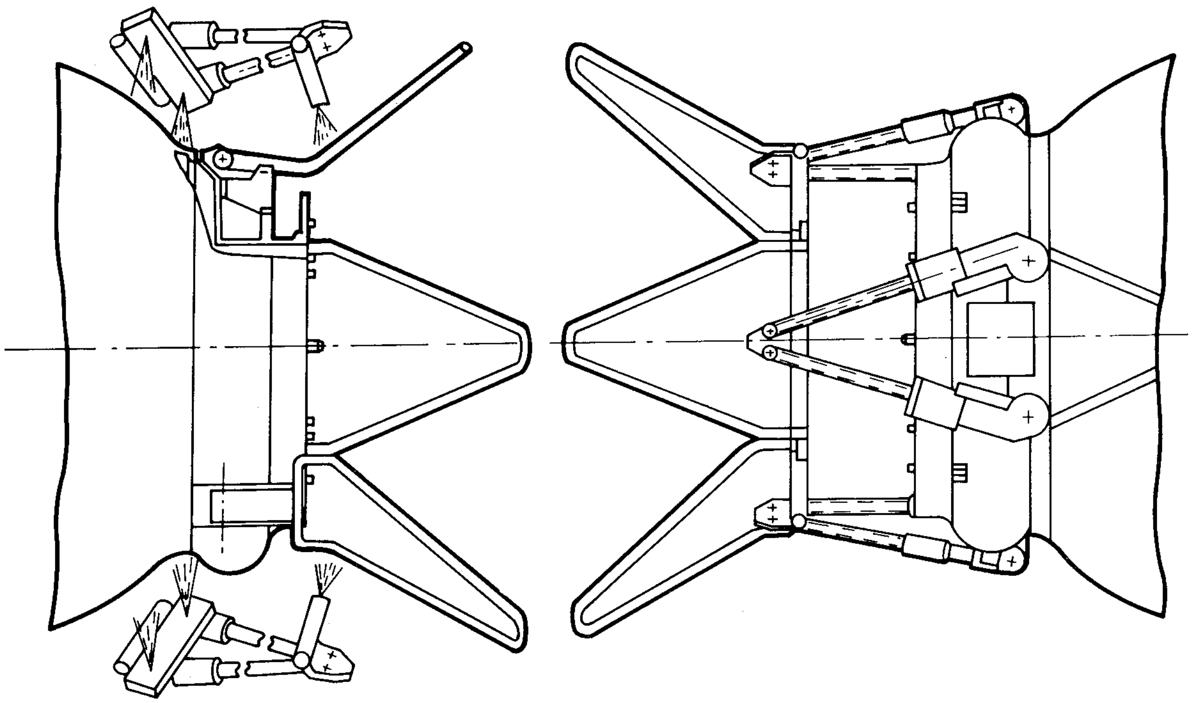

Figure 3. - Emergency assembly jettisoning and docking preparation.

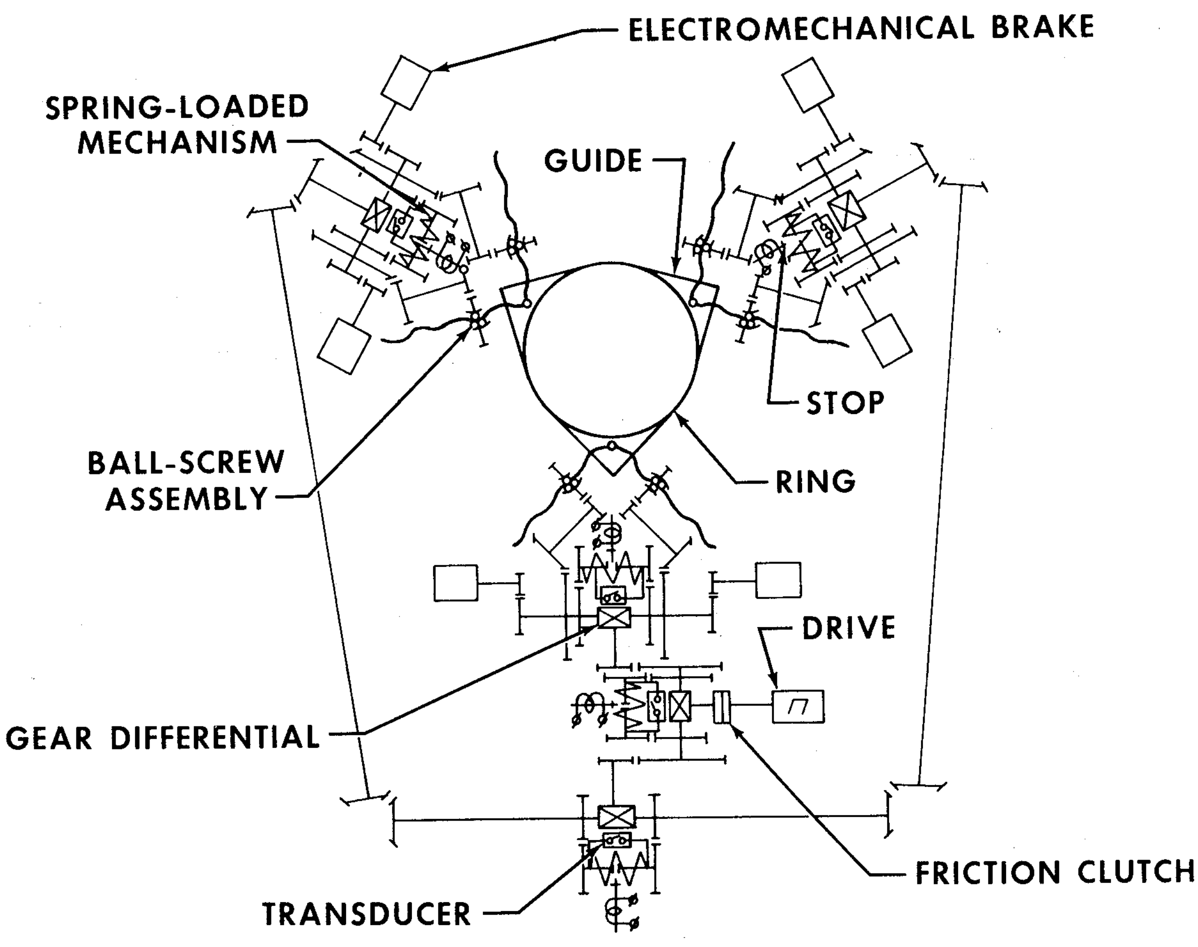

Figure 4. - Assembly synchronization.