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STRUCTURAL LATCHES FOR MODULAR ASSEMBLY OF SPACECRAFT AND SPACE MECHANISMS

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ABSTRACT

Latching techniques are changing from early approaches due to the advent of berthing technology. Latch selection for a given interface may be conducted by evaluating candidate capabilities which meet functional interface requirements. A judgment criteria system is presented along with an example of its use in choosing the Rollerscrew Structural Latch (RSL) for the NASA Flat Plate Interface Prototype (FPIP).

Details are given on Rollerscrew operation, design, and development difficulties. A test plan is also outlined for the RSL and FPIP.

INTRODUCTION

Assembling spacecraft systems from modular sections has changed the role of structural latching systems. Previous approaches based on docking methods have given way to controlled berthing techniques using end effector and robotic arm systems. Latches are now required to operate reliably over many connect/disconnect cycles and multi-year lifespans. Interfaces can be brought into near-intimate contact and alignment before structural attachment is initiated. These refinements have allowed the use of both latch and fastener techniques for the structural connection of spacecraft and payload interfaces.

TUTORIAL

The primary functions of a latching system are to acquire, hold, and release one object from another. This is usually done by moving some part of a fixed structure into the path of a moveable structure so as to prohibit relative motion between the two. Key features of this concept are

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(1) a fixed structure to which a latch is mounted; (2) a moveable structure that is to be latched to the fixed structure; (3) the path of the moveable structure must be controlled relative to the fixed structure; (4) a method must be available by which the latch may grasp or capture the moveable structure; and (5) the capture action must be defined by the latch mechanism.

Most interfaces share connection integrity between three basic elements: (1) the structures to be assembled; (2) an alignment system; and (3) a mechanical latching system. These elements correspond to the key features of the latching function. Spacecraft docking interfaces share torsion, shear and compression loads between the structure and alignment subsystems, while tension and bending are reacted by structure and latching subsystems. Structure and alignment subsystems are usually passive in operation with latches being active.

Every connectable interface has unique characteristics that govern the configuration and operation of its latching system. The goal of the latch engineer is to match the characteristics of a latch system to the functional requirements of the mating interface. Latch selection can consist of seven phases:

(1) Definition of Functional Latch Requirements
(2) Proposal of Candidate Techniques
(3) Establishment of a Weighted Judgment Criteria
(4) Selection of Final Candidates per Weighted Criteria
(5) Formalization of Functional Latch Requirements
(6) Optimization of Final Candidates to Functional Requirements
(7) Selection of a Final Latch System per Weighted Criteria

Functional latch requirements are often difficult to define early in a program. Table 1 outlines functional characteristics of latch systems that must be understood prior to functional requirement definition. Several varied latching techniques should be proposed for initial evaluation to provide a good cross section of available latching technology. Establishment of a weighted judgment criteria for candidate selection offers an objective decision process for concept evaluation. Selection of final candidates from early proposals allows competitive development toward a latching system best optimized for each interface application. A final latch system can then be selected that represents the optimum choice for interface operation.

TABLE I

FUNCTIONAL CHARACTERISTICS OF LATCH SYSTEMS

I. BASIC CHARACTERISTICS

(A) LOAD CHARACTERISTICS
(B) OPERATIONAL CHARACTERISTICS
(C) ENVELOPE
(D) POWER AND SIGNAL
(E) MASS
(F) ENVIRONMENT
(G) LIFE, RELIABILITY
(H) MARGINS, SAFETY FACTORS
(I) COST
(J) SCHEDULE
(K) MISCELLANEOUS REQUIREMENTS
(L) QUALIFICATION

II. LOAD CHARACTERISTICS

(A) LOAD SPECTRUM
  (1) STATIC
  (2) DYNAMIC

(B) DIRECTION
(C) PRELOAD
(D) PUSH-OFF
(E) TAKE-UP
(F) ADJUSTABILITY
(G) ENVIRONMENT
(H) STIFFNESS
(I) MISCELLANEOUS

III. OPERATIONAL CHARACTERISTICS

(A) PHASE CHARACTERISTICS
  (1) CAPTURE
  (2) ENGAGEMENT
  (3) TAKE-UP
  (4) PRELOAD
  (5) STRUCTURAL LOAD
  (6) UNLATCH
  (7) RELEASE CHARACTERISTICS
  (8) EMERGENCY OPERATIONS
  (9) INSTALLATION AND MAINTENANCE

(B) ACTUATION DYNAMICS
(C) ACTUATION TIME
(D) DIRECTION
(E) POWER
(F) RATE
(G) ALIGNMENT
(H) RELIABILITY
(I) ENVIRONMENT
(J) LIFE
(K) TESTING
(L) OTHER MISSION SPECIFIC REQUIREMENTS

Setting up a weighted judgment criteria is purely a subjective process. Both required and desired characteristics that affect design, operation, fabrication, and management of the interface should be weighted relative to importance. Following this, latch candidates must be evaluated for capabilities in each area and have the weighing factors applied to obtain an objective capability value. Similar selection methods are widely used for the evaluation of spacecraft systems.

Most common spacecraft latch systems in use today are based on actuated hooks or threaded fasteners. While these devices seem very different, they are quite similar in function. Both systems rely on the interlocking of piece parts to retain an object, but differ in their axis and type of movement. Each system has advantages and disadvantages relative to interface requirements.

The primary advantages of hook systems are rapid actuation and high misalignment tolerance. The major disadvantage is that length and preload are relatively fixed. Threaded fastener systems are variable in preload and length but require finer alignment and are slower in actuation than hooks. Fasteners and hooks are complimentary technologies with specific applications in aerospace latching.

Docking systems in the past have incorporated hook systems because of their rapid actuation and relatively high misalignment tolerance, which is useful during interface capture. Berthing technology has reduced the necessity for rapid actuation because closing velocities are low and alignment is more controllable. Fastener systems with reach and alignment flexibility are being developed for connector and standard interface systems where close prelatch orientation is available.

Spacecraft coupling is controlled by both the latch actuation mechanism and its drive system. Often the mechanism to control latch translation is more complex than the interfacing latch element itself. Linkage systems on hook latches and advance/retract mechanisms on powered fasteners correspond and guide the configuration of each system. From a drive standpoint, both linkages and threads act as gear stages with loads being fed back into the motor system.

A problem with both hook and fastener systems is load control. Hook system preload is traditionally preset by rigging. Load changes due to thermal and dynamic fluctuations cannot be compensated under normal circumstances.

Fastener systems usually control load through their drive systems by either power control, active feedback through a sensor system, positional sensing, or mechanical control, such as a clutch system.

LATCH SELECTION FOR THE NASA FLAT PLATE INTERFACE PROTOTYPE

The Flat Plate Interface Prototype (FPIP) is an integrated modular connector designed to transfer thermal energy, electrical power, and signal data between two structures. This interface system is being developed by TRW's Electronic Systems Group for NASA GSFC, under contract number NAS 5-30080. Figures 1 and 2 illustrate both sides of the prototype design and full-scale mock-up respectively. The FPIP consists of two thermal transfer structures with very flat mating surfaces, a split core power transformer system, an optical data transfer system, a load distribution system, and a central latching system. Thermal heat sinking is accomplished by compressing the structures together under a uniform load generated by the latch through the load distribution system. Requirements on the latching system include high load capability, limited contaminant generation, high reliability and life, and controlled load capability. Functional requirements for this latch system are listed in Table 2.

TABLE 2

FUNCTIONAL REQUIREMENTS FOR THE FPIP LATCH

o	Structural Preload	$\geq$ 3,600 Kg (8,000 Lbf)
o	Ultimate Load	$\geq$ 6,800 Kg (15,000 Lbf)
o	Take-Up Load	$\geq$ 225 Kg (500 Lbf)
o	Preload Adjustable up to	4,550 Kg (10,000 Lbf)
o	Actuation Time	$<$ 100 sec.
o	Lateral, Longitudinal Misalignment	$\leq$ 3 mm (.125 in)
o	Angular Misalignment	$\leq$ 2 Degrees
o	Mass	$\leq$ 20 Kg (40 Lbm)
o	Life	$>$ 1,000 Cycles Over 10 Yrs
o	Power	TBD @ 28 Vdc
o	Negligible Particulate and Gaseous Contamination	
o	Simple Operation, EVA Compatible	
o	Full Retractability into Interface, Damage Resistant Design	
o	Full Accommodation to the TRW Load Distribution and Flat Plate System	

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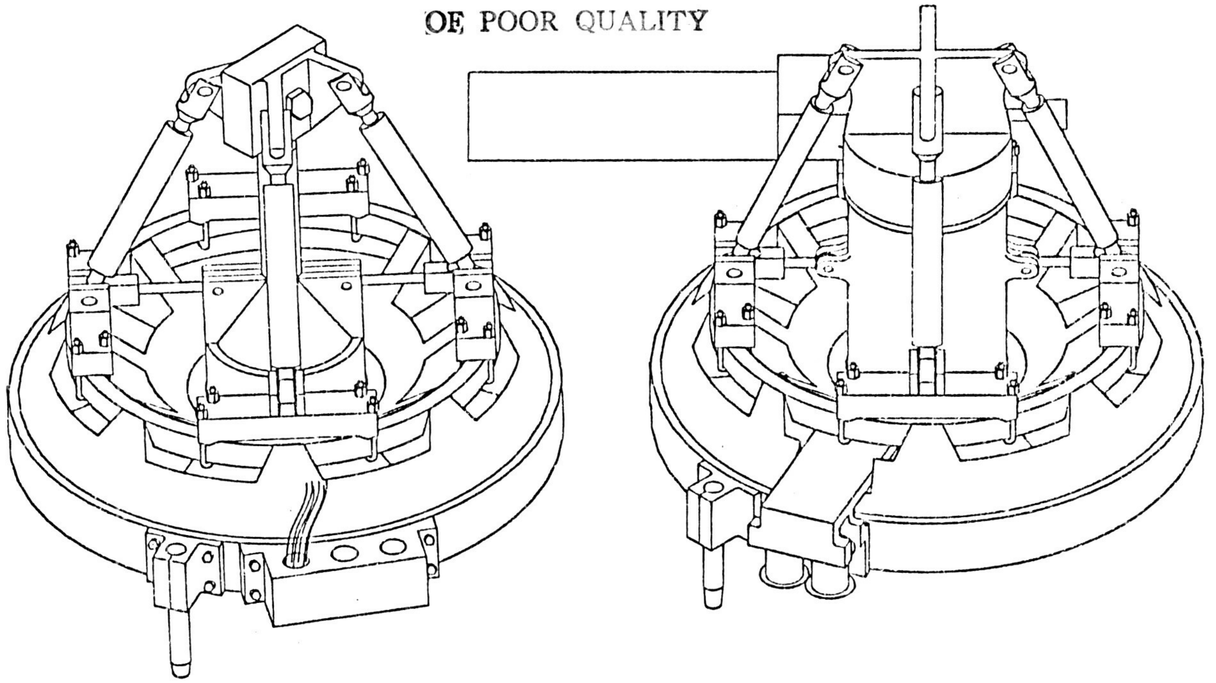

FIGURE 1

FLAT PLATE INTERFACE PROTOTYPES (TYPE I AND TYPE II)

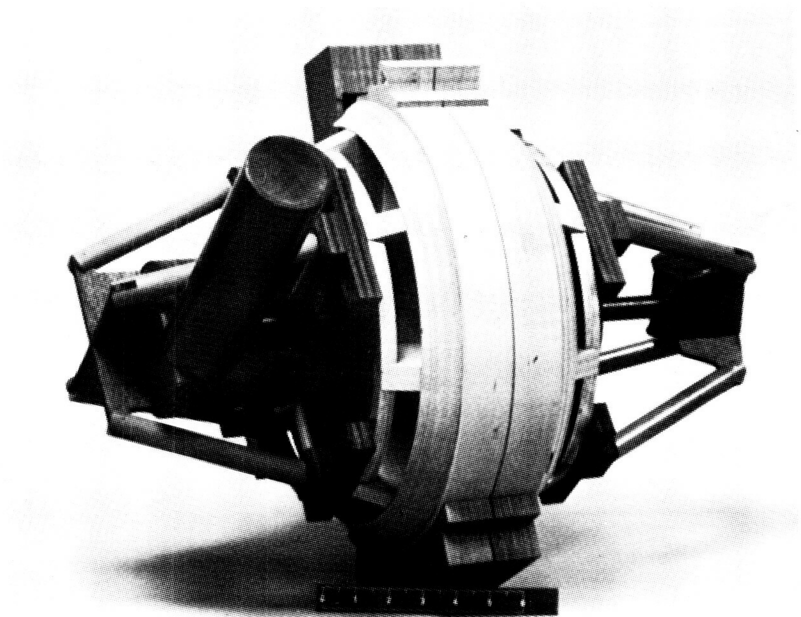

FIGURE 2

FULL SCALE FLAT PLATE INTERFACE MOCK-UP

The FPIP does not require gross alignment capacity or rapid engagement. High preload generation, reliability, life, and low contamination are mandatory to the operation of the FPIP system. Candidate latching concepts included a powered pawl latch, a Rollerscrew Structural Latch, a powered claw latch, and a powered nut/bolt latch system. Latches were evaluated against a weighted judgment criteria, as shown in Table 3. The powered pawl latch and Rollerscrew latch were chosen as preliminary candidates due to their limited sliding contact in the area of the interface.

TABLE 3

WEIGHTED JUDGMENT CRITERIA

(PRELIMINARY EVALUATION)

ITEM	CRITERIA	WEIGHT FACTOR (1-10)	FIXED ACME		POWERED NUT/BOLT		ROLLERSCREW		POWERED PAWL	
			VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
1	COST	8	4	32	5	40	3	24	5	40
2	SIMPLICITY	5	4	20	4	20	3	15	4	20
3	FUNCTION	9	7	63	6	54	9	81	8	72
4	MASS	4	5	20	6	24	3	12	5	20
5	POWER	4	5	20	5	20	7	28	6	24
6	LOAD	9	7	63	8	72	9	81	8	72
7	ENVELOPE	7	4	28	7	49	5	35	5	35
8	RELIABILITY/LIFE	9	5	45	4	36	9	81	8	72
9	SERVICE/MAINTENANCE	5	5	25	4	20	7	35	8	40
10	ENVIRONMENT COMPATIBLE	9	5	45	4	36	8	72	7	63
11	SAFETY	5	4	20	5	25	6	30	5	25
12	DESIGN FLEXABILITY	4	4	16	6	24	8	32	7	28
13	DESIGN MATURITY	2	5	10	6	12	4	8	8	16
14	OPERATION SIMPLICITY	7	7	49	8	56	9	63	7	49
15	ELECTRONICS COMPLEXITY	5	5	25	6	30	6	30	5	25
16	SCHEDULE	6	5	30	5	30	5	30	6	36
17	MISCELLANEOUS FACTORS	7	7	49	7	49	7	49	4	28
18	CONTROL	7	5	35	5	35	7	49	6	42
	TOTALS			595		632		755		707

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At this point, latch optimization began as each system was refined. Changes to the Rollerscrew system included structural revision to fit into the load distribution system, contamination control by a wear-in process with multiple clean-up stages, drive system revision to comply to customer request and test requirements, and variable load control through mechanical and electronic techniques. Pawl latch changes included structural revision and variable load control.

A final evaluation was made using the previous judgment system, resulting in the Rollerscrew Structural Latch being chosen as Rexnord's primary candidate for the FPIP docking mechanism. The major criteria that affected this decision were function, environmental compatibility, operational simplicity, cost, and miscellaneous factors. The Rollerscrew latch and pawl latch are very similar with many common components. Both latches would work well for this application. The pawl latch, however, had minor drawbacks in its design and operation, such as additional components, including the hook and its control system, a motion reversal during actuation, and sliding surfaces in the hook/receptacle area.

THE ROLLERSCREW STRUCTURAL LATCH

Construction and Operation

The Rollerscrew Structural Latch (RSL) Assembly is shown in Figures 3 through 9. Figure 3 is an isometric view of the entire assembly while Figures 4 and 5 are photographs of the Rollerscrew Assembly and the Rollernut Receptacle. Figures 6, 7, and 9 show cutaway views of the Rollerscrew Assembly and the Receptacle Assembly. The latch is powered by a brushless DC motor that has been modified for vacuum use through a worm gear drive system that is torque limited by a slip clutch, as shown in Figure 9. A flange at the base of the Screw is driven by an internally splined spool which is connected to the worm gear assembly.

To engage, the drive system advances the Screw through a guide system until its drive flange bottoms. The Screw threads into a floating receptacle and tightens, preloading the interface. When engagement and take-up phases are complete, power is increased to obtain a predetermined load. On full load the motor stalls and is shut down, completing latch-up.

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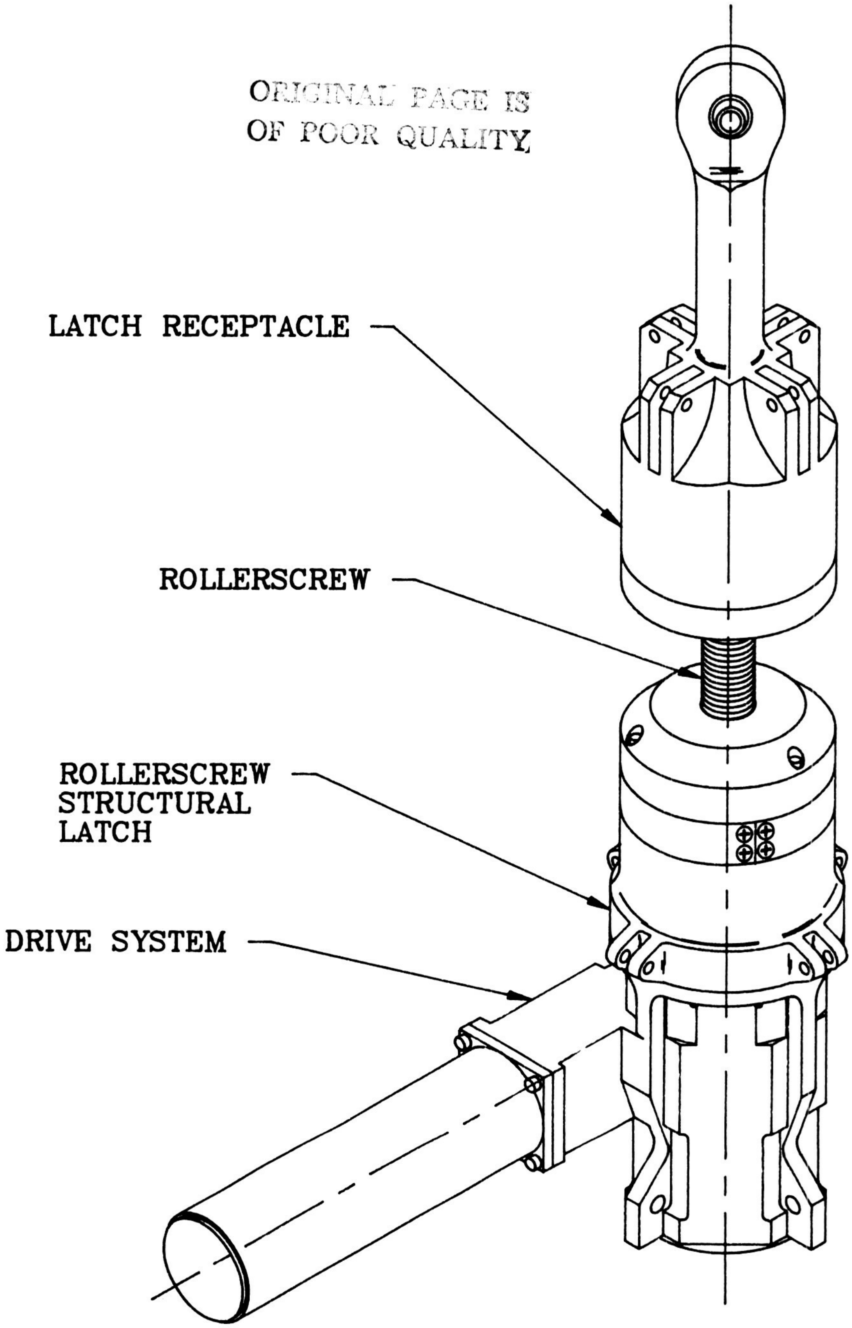

FIGURE 3

ROLLERSCREW STRUCTURAL LATCH SYSTEM

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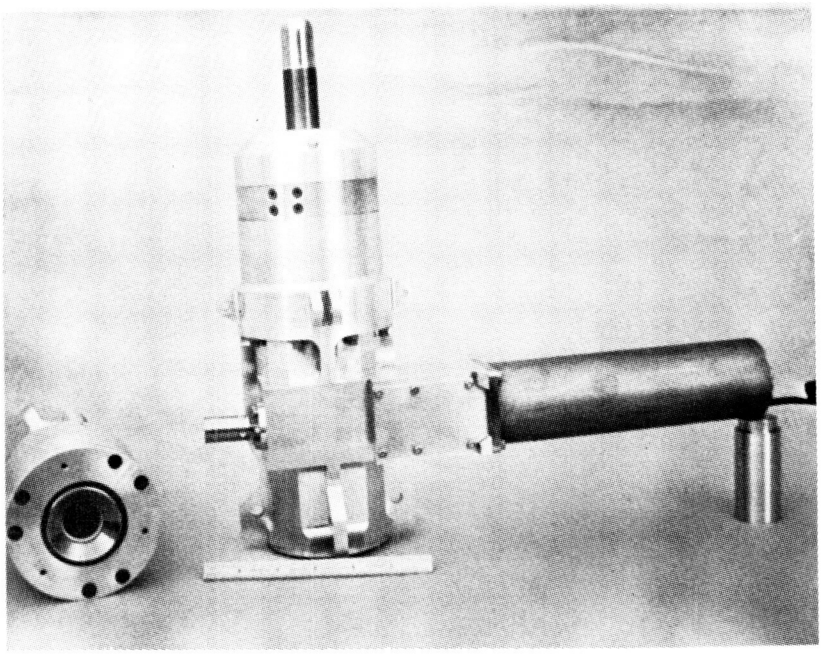

FIGURE 4

RSL ASSEMBLY

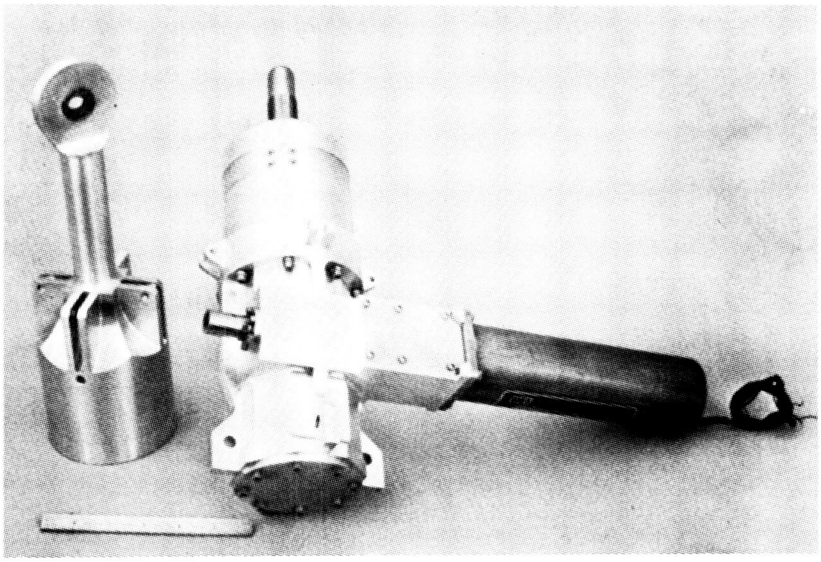

FIGURE 5

LATCH ASSEMBLY

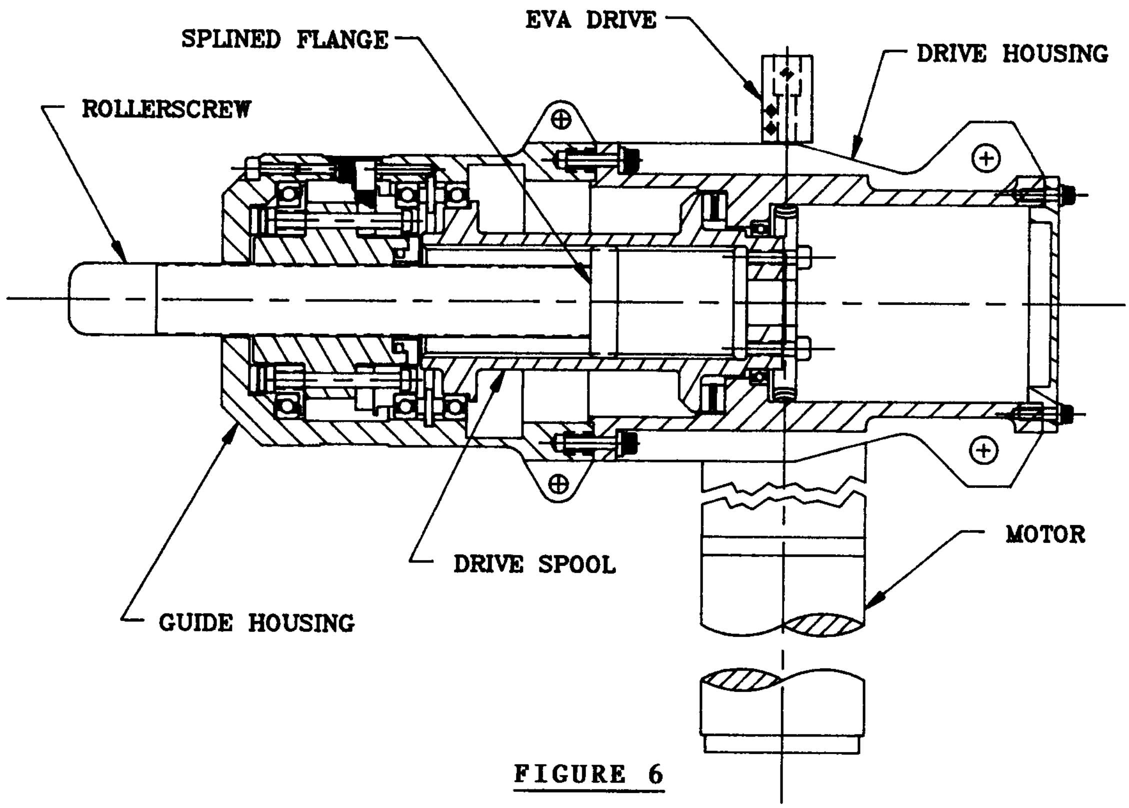

FIGURE 6

ROLLERSCREW LATCH ASSEMBLY

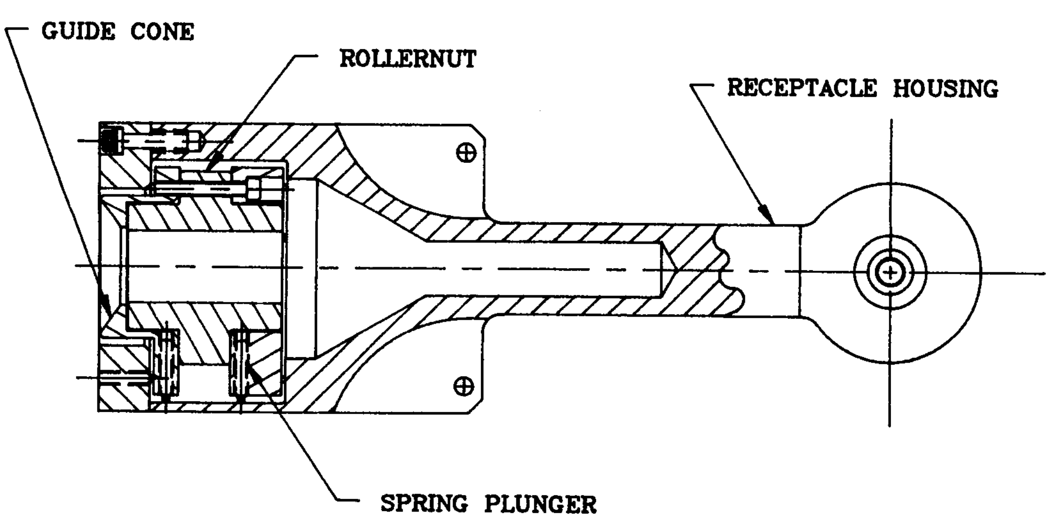

FIGURE 7

RECEPTACLE ASSEMBLY

For interface demate, the motor direction is reversed, un-screwing the Rollerscrew from its receptacle and retracting it back into the RSL housing. The motor drive is then shut down.

The Rollerscrew Structural Latch will not loosen preload over extended periods due to worm gear ratio, back drive efficiency, and motor detent torque. No periodic maintenance is planned for this device.

The Rollerscrew/Nut System

The primary element of the RSL is the Rollerscrew and Nut, as shown in Figure 8. A recirculating Rollerscrew was chosen for this application primarily because of its reliability. The Rollerscrew/Nut uses rolling elements as a thread interface, which reduces sliding friction to a minimum. The Nut resembles a rollerbearing with threads. Reduced friction allows high loads to be generated with low input torque, reducing power requirements. The hardened components and materials used in the Nut decrease the opportunity for cold welding over extended load lifetimes. If any degradation or contamination occurs, the Rollerscrew and Nut are very damage tolerant. Rolling element mechanisms with high torque margins insure good reliability.

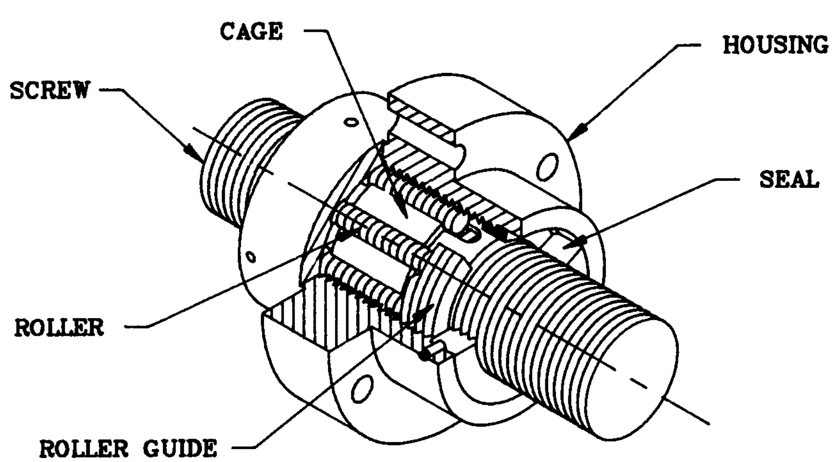

FIGURE 8

RECIRCULATING ROLLERSCREW NUT

The primary failure mode for Rollerscrews is structural overload. Beyond rated loadings the threads or rollers may brinell, causing rough action and decreased efficiency. As loading is increased to failure, roller breakage occurs. A recirculating Rollernut was chosen for this application, partially because it features a cage which reduces the tendency to jam on massive overload failure.

Other Rollerscrew failure modes include over-speed, which is not a problem with this device, and re-entry of the rollers inside the housing. No history of re-entry failure has been reported for Rollerscrews; however, this can be a problem with ball-screw systems. A Rollernut uses caged rollers articulated by a cam system for positive control.

The Rollerscrew/Nut are commercially available items modified to engage and disengage smoothly. Materials used for this system are 4140 steel screw, 52100 nut and rollers, 440C stainless case, and a Teflon seal. Screw and Nuts are dry-lubricated with tungsten disulfide, then run-in and cleaned to reduce particle generation.

DESIGN CONCERNS AND SOLUTIONS

Major concerns which arose during the design of the RSL are as follows:

- Thread Engagement
- Gear System Operation
- RSL Load Control
- Clutch Operation
- Contamination Control

Threading engagement is potentially difficult for Rollerscrews under misaligned conditions. The Rollernut has a 25 mm (.984 inch) diameter thread with a pitch of 1.0 mm (.040 inch). Eleven rollers within the Nut define a pick-up window of .09 mm (.004 inch). Under misaligned conditions the lead window can be missed, cross-threading the Screw and jamming the Nut. A large bullet nose on the Screw coupled with modifications to the internal mechanism of the Nut and lead thread of the Screw eliminated cross-threading concerns.

The worm gear drive system presented difficulties that affected primarily the powertrain efficiency and consistency. Efficiency became a problem when design equations predicted anywhere from 17% to 60% power transmission. Consistency was required because motor power is to govern latch preload.

Losses or gains through the gear train have a direct effect on RSL preload. Gear train stiffness, alignment, and backlash that can affect latch operations have been addressed in the design process.

Worm gear efficiency equations are based on commercial gear reducers with oil bath lubrication running at constant RPM. Worm efficiency can vary due to any number of variables, such as materials, lubrication, rubbing speed, alignment, stiffness, profile, and wear. A statistical average was taken to approximate a theoretical design value for initial motor and clutch sizing. Verification tests are to be run to establish an empirical value for this gearset. However, every gearset is individual and these measurements may have limited design value.

Gear stiffness was found to be marginal on initial designs, and was increased by increasing shaft size, changing assembly techniques, revising housing design, and mounting with preloaded bearing sets, as shown in Figure 9.

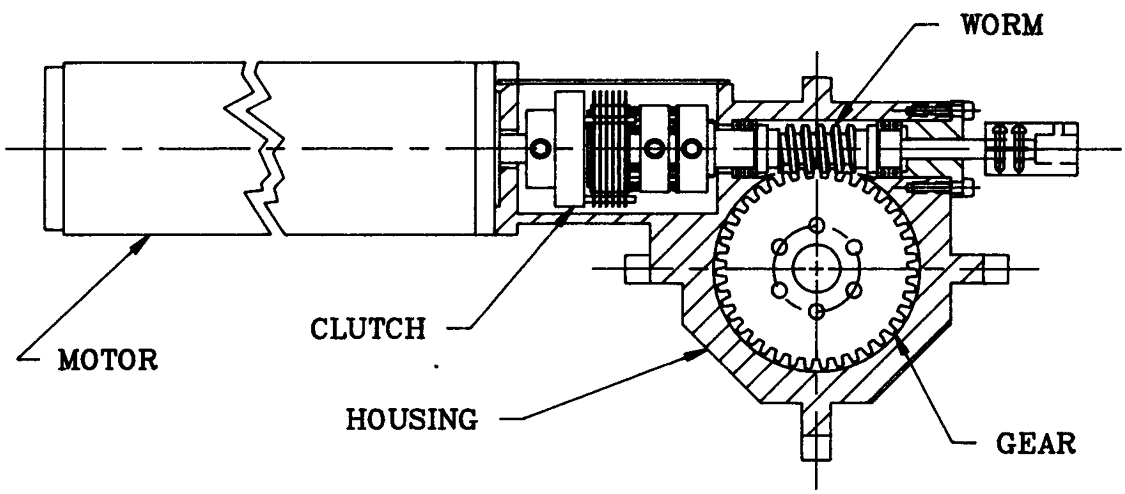

FIGURE 9

ROLLERSCREW DRIVE SYSTEM

To obtain constant load readings, worm sets must be run-in under conditions similar to actual service. The worm is hardened and ground 1045 steel and the gear is Amco Alloy #45 Phosphor Bronze. The worm and gear are lubricated with both tungsten disulfide and Braycote 601 grease.

Load control for the RSL is accomplished by a two stage actuation with motor power determined by current limiting devices. This method allows accurate preload to be consistently applied. A single stage actuation was considered where the drive system is powered to stall, but variables in drive system inertia could vary preload levels beyond acceptable limits.

A polymetric slip clutch was originally used to control RSL preload. Difficulty in predicting a change in friction coefficient between ambient air and vacuum conditions precluded this approach. Commercially available materials could vary in friction coefficient by as much as 2 to 1 between air and vacuum operation. The clutch has been relegated to an overload protection role.

The RSL addresses contamination in a number of ways. Rolling element latch interfaces were selected, in part, to reduce particle generation. In addition, Teflon wiper seals have been added to control any loose particles in the RSL and Receptacle Nut. Both RSL and Receptacle housings are covered, with the exception of the Screw and Nut interfaces. A run-in and clean-up procedure reduces particle generation from initial actuations. Gaseous contamination is reduced by the use of liquid lubrication only in the worm gear area, deep within the housing.

TESTS PLANNED FOR THE RSL AND FPIP

At the time of submittal of this paper, acceptance testing of the RSL was just commencing. Planned testing of the RSL includes calibration of preload versus motor power, life cycling, and misalignment capability tests. Planned testing at the systems level will include cycling tests as well as functional tests of the FPIP system in a vacuum. Results of both the RSL and FPIP tests will be reported as a supplement to the presentation at the Symposium.

CONCLUSIONS

This paper has presented a brief tutorial and evaluation procedure for interface latch selection. An application of this technique is discussed with detail about its operation, construction, and design development.

The Rollerscrew Structural Latch is a viable candidate for interface latching. Careful design and application are required to utilize the Rollerscrew as an autonomous latching/fastening device. The result of this effort promises a significant increase in reliability over standard nut/bolt fastener systems.

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