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FINAL REPORT
NAS8-11565
CONTROL NR. 1-4-84-00010-01 (IF)
CPB02-1019-64

MULTI-DEGREE OF FREEDOM OSCILLATOR

FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER

PREPARED BY
JOHN MELONAS

MARCH 11, 1965

SPACO, INC.
HUNTSVILLE, ALABAMA

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INTRODUCTION

In accordance with the contract NAS8-11565 issued November 1, 1963 SPACO designed and fabricated a multi-degree of freedom oscillator capable of inducing controlled sinusoidal motions for test studies. The purpose of the oscillator was to study the slosh patterns produced in the Saturn LOX tanks by subjecting a scaled-down model tank to simulated test motions experienced by the full size vehicle. The controlled vibratory motions stipulated in the original specifications were as follows:

Direction of Motion	Amplitude	Frequency
Horizontal (Pitch)	3 inches	6 cps
Horizontal (Yaw)*	3 inches	6 cps
Nutation (Roll)**	± 6 degrees	6 cps
Vertical	. 6 inches	12 cps

In addition, provisions had to be made for individual or synchronous control of each motion with respect to any one or all other motions simultaneously. Furthermore, motions could be leading or lagging one another by a controlled phase shift ranging from 0° to 360°. In other words, all motions could begin their cycles at the same instant or one or more motions could be made to lead or lag (in phase) the referenced frequency.

This report relates primarily to the activity performed during the last phase or the final development period of oscillation.

* Same plane as Pitch but right angles.
** Rotation through approximately 5° about the vertical axis.

BASIC DESIGN CONCEPTS

Two basic design concepts were tried before the unit was developed to a workable state. The first attempt consisted of a relatively light weight structure which failed to meet satisfactory performance largely due to inadequate bearings supporting the test vessel. The second concept incorporated massive heavy weight structures designed to rigidize the test vessel supports. Photographs of the final system after development are attached to this report.

DEVELOPMENT WORK

Increasing the size and weight of the second structure introduced many new problems. The greatest problem was reflected in the mechanical drive systems of the pitch and yaw and in the hydraulic piston drive of the vertical motion. Other problems included electrical failures and extraneous mechanical motions.

Hydraulic Drive System

First of all the hydraulic drive system of the verticle drive was converted to a mechanical drive system. Difficulties experienced by the hydraulic system included gradual climbing of the test tank during operation (indicating leak-by across the pistons), and also the occurrence of resonance at approximately 4 cps and up. Conversion to a mechanical system eliminated these problems and displayed good performance.

Mechanical Drive Systems

The mechanical drive systems of the pitch and yaw modes were subjected to extremely high loading pressures which induced galling. The drives consisted essentially of a slider crank mechanism incorporating a roller bearing against a flat surface. Thus, the high loads coupled with low bearing areas induced galling. Increasing the surface hardness from R_C40 to R_C50 resulted in slight improvement in performance, but galling continued to take place in the drive systems. It appeared at this point that an increase in bearing areas was the only feasible approach for correcting the galling problem. The drive bearings were therefore encased in hardened slide blocks and to reduce the friction of the sliding contacts all rubbing surfaces were coated with a baked on film of molybdenum disulfide. This resulted in somewhat higher load capacity but eventually galling again occurred. Finally, the slide blocks within the drives on which the bearing blocks rubbed were replaced with oil impregnated bronze plates. This combination of materials (i. e. hardened steel against oilite bronze) proved to be far superior to all others attempted and eventually was adopted for the pitch, yaw and vertical drives.

Lightning Holes

Concurrent with the design of the mechanical drive systems was an analytical study of the superstructures - all frame work extending above the plane of the mechanical driving forces of the pitch and yaw systems. It was reasoned that if the weight of these structures could be reduced at no sacrifice to the strength of the supporting members, inertial moments would be lessened, resulting in not only truer sinusoidal motion at the test tank area, but also in greater load reduction on the drive members. Results of this analysis showed that approximately 300 pounds could be cut from the super-structure with a simultaneous result of increased rigidity of the structure. This was possible because the material removed tended to reduce the moment (pounds of material x distance from plane of driving force) at a faster rate than the corresponding reduction in 'I' (moment of inertia of the structural member). Of course, the weight had to be taken from the non critical structural areas, i. e. web sections of the wide flange and 'I' beams in order to accomplish this.

Electrical Modifications

Due to high amperage demand requirements of the pitch and yaw motors when starting, the SCR's originally designed onto the system were continually failing. It was found necessary to replace these low value SCR's by approximately double the capacity. Subsequent electrical problems were associated with the precision fuses installed in the pitch and yaw circuits. Replacing these with industrial type fuses solved the final problem encountered electrically. Specifications of the industrial fuse proved to be compatible with the motor demand requirements yet provided adequate protection for the SCR's.

Miscellaneous Modifications

One important modification was made to the drive yaw plate. This plate, approximately 3-inches by 9-inches by 50-inches, formed part of the pitch frame. To this plate is bolted the yaw drive assembly and at high loads, was noted to bend and twist severely. To remedy this condition the plate was milled to receive a block which was anchored to the bottom plate of the main stationary frame and also to the (stationary) guide rail parallel to the pitch motion. The yaw plate was slotted to allow the required 3-inch amplitude of pitch motion between the yaw plate and block. This arrangement helped steady the yaw drive member in both bending and twisting.

To further reduce the twisting action in this area, the body sizes of the bolts attached to each end of the member were increased to a condition of no clearance between bolt and hole.

Other problem areas which were rectified included; (1) post weld warpage of the super-structure, a binding condition between tank cage and superstructure bearing resulting from hole cutting operation, (2) adjustment of pitch amplitude assembly to prevent binding in the adjoining bearing areas (3) replacing the direct coupled drive with a free floating drive between the pitch drive shaft and the eccentric throw assembly in order to eliminate binding in this area, and (4) adjustment of shims between sliding and stationary base plates to reduce extraneous vertical motions.

TEST RESULTS

After completing the development work, the unit was subjected to a qualification test, whereby each mode of operation was driven at various combinations of amplitude and frequency. The intended frequency was controlled by the corresponding panel meter. The actual frequency was measured from the direct plot of data of the visicorder.

Each test was designed to last 3 1/2 minutes, a duration determined from past experience to provide ample time for completion of a test. During each test the operation was closely monitored by means of sight and sound, in addition to the instrumented data. During two of the tests, bearings were noted to overheat, indicating critical operating conditions. These tests are indicated by asterisks on the test data sheet of this report. The corresponding "G" level for these modes represents the upper allowable limit for each mode. In fact, operating time at these levels in future tests must be extremely short - probably not to exceed 1 minute. All other test settings functioned satisfactorily.

CONCLUSIONS

(1) The multi-degree of freedom oscillator was completed and functions satisfactorily.

(2) Test data indicate essentially sinusoidal motions for all modes and generally very good overall operation.

(3) The limiting factor of the unit is the drive system. Approximately 2 G's is the maximum recommended limit if lasting performance is to be expected.

MULTI DEGREE OF FREEDOM OSCILLATOR TEST RESULTS

January 9, 1965

Mode

	Mode	Displacement	Frequency Gage	Frequency Actual	General Performance	Meter Calibration
	Pitch	1.376"	1cps	1cps	Good	Good
	Yaw	1.460	1cps	1.03 cps	Good	Good (3%)
	Vertical	.285"	1cps	1.08	Good	Needs Recalibration (+8%)
	Pitch	1.376	2cps		Good	Good
	Pitch	1.376	3cps	3.03	Good	Good (1%)
	Pitch	1.376	4cps	4.08	Good	Good (2%)
	*Pitch	1.376	5cps	5.10	Bearing Overheated	Good (2%)
	Yaw	1.460	1cps	1.03	Good	Good (3%)
	Yaw	1.460	2cps	2.02	Good	Good (1%)
	Yaw	1.460	3cps	3.03	Good	Good (1%)
	Yaw	1.460	4cps	4.04	Good	Good (1%)
	*Yaw	1.460	5cps		Bearing Overheated	Good
	Vertical	.285	2cps	2.14	Good	Needs Recalibration (+7%)
	Vertical	.285	4cps	4.14	Good	Good (+3 1/2%)
	Vertical	.285	6cps	6.40	Good	Needs Calibration (+6.8%)
	Vertical	.285	8cps	8.64	Good	Needs Calibration (+8%)
	Vertical	.285	10cps	10.80	Good	Needs Calibration (+8%)
	Vertical	.285	12cps	13.00	Good	Needs Calibration (+8%)
	Pitch	.750	6cps	6.06	Good	Good (1%)
	Yaw	1.00"	6cps	6.21	Good	Good (3 1/2%)
	Pitch	2.00	4cps		Good	Good
	Yaw	2.00	4.5cps		Good	Good
	Vertical	.60	8cps	8.6	Good	Needs Calibration (8%)
	Pitch	1.00	cps	4.3	Good	
synchronous operation 90° out of phase	Yaw	1.00	cps	4.3	Good	
	Vertical	.600	cps	4.3	Good	
	Pitch	1.00	4.8cps	4.3	Good	
	Yaw	1.00	4.8cps		Good	

*This set of conditions corresponds to "G" level representing absolute maximum of machine capability for periods shorter than 2 minutes.