THE EFFECT OF SPACE ENVIRONMENTS FACTORS ON SPACECRAFT STRUCTURE

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ABSTRACT

This work covers the investigation of the effects of space environments factors on spacecraft structure. The satellite operates on a low earth orbit at circular (500,500) km, and subjected to different torques in space environments.

The purpose of this paper is to develop the satellite structure design and test it to obtain the mechanical behaviour of structure. The satellite used so far is spin – stabilized, and rotating about one axis in 3 rpm. A configuration to the structure is suggested to be hexagonal; the dimension of structure is 110cm in diameter and 85cm high.

The general static and dynamics tested of the system are verified, and analyzed to find the stress, strain, and vibration on the structure.

الخلاصة

يتضمن العمل بحث تاثيرات العوامل البيئية الفضائية على هيكل القمر الصناعي. يعمل القمر الصناعي على مدار ارضي منخفض بنصف قطر (500, 500 km) يتعرض الى عزوم التوائية مختلفة في الظروف الفضائية.

الغرض من هذا البحث هو تطوير نموذج لهيكل القمر الصناعي وفحصه للحصول على السلوك الميكانيكي له. ان القمر الصناعي المستخدم سابقا stabilized spin حيث يدور حول محور واحد بسرعة 3rpm تم اقتراح الهيكل من النوع السداسي بقطر 120cm وبارتفاع 85cm تم الحصول علي السلوك الستاتيكي والديناميكي لايجاد الجهادات والترددات الطبيعية للهيكل.

KEY WORDS

Spacecraft structure, satellite, space environments, vibration

INTRODUCTION

A satellite structure must fulfil various requirements. First of all, must resist the loads induced by the lunch environment (acceleration, acoustics thermal). Met all the functional performances required on orbit such as dimensional stability for example. The concept must be compatible with the standard manufacturing process and use standard components (sheet-iron, tube whenever possible) every time it is possible.

The spacecraft structure is a complex shape and cannot be described analytically. The use of finite element analysis software package such as NASTRAN makes it possible to model structures mathematically in great detail.

The finite element analysis can sometimes lead to errors up to 40% in dynamic models. So the structural testing required to qualify an assembly for launch is often accomplished by subjecting a prototype to static and dynamic loads in excess of those anticipated for flight and actual unit is subjected to near flight levels.

The experimental work is the best way to verify the theoretical models. In the literature there are several experimental setups and procedures for such task. [Military Standard, 1982][Knight, 1996] from these experimental setups and procedures of measurements, the test rig constructed is a quarter scale flight model. The raw materials used for subsystem are tested, qualified, and accepted for low earth orbit Satellite.

After system assembly, the strains & stresses were obtained by the strain test. The natural frequency, amplitude, mode shape and transient response that characterize the mode of vibration were obtained by the dynamic test.

DEVELOPMENT TESTING

The objective of he development tests is to assure that testing of critical items at all levels of assembly is sufficient to validate the design approach.

A structural development test is also needed to verify the stiffness properties of the space vehicle and to measure member load and stress distribution and deflections in structures with redundant load paths.

STRUCTURAL STATIC LOAD TEST

This test demonstrates the adequacy of the structure to meet requirements of strength or stiffness, or both, with the desired design margin when subjected to simulated critical environments, such as temperature and loads, predicted to occur during its service life.

The structural configuration materials and manufacturing processes employed in the qualification test specimens were identical to these of flight articles.

Static loads representing the design limit load and the design ultimate load were applied to the structure, and measurements of the strain and deformation recorded. Strain and deformation were measured before loading, after removal of the limit loads, and at several intermediate levels up to limit load for post-test diagnostic purposes.

The test conditions include the combined effects of pressure, preloads and temperature. These effects can be simulated in the tests as long as the simulations envelop the failure modes and design margins. For example temperature effects, such as material degradation and additive thermal stresses can often be accounted for by increasing mechanical load [Hobbs, 1996].

DYNAMIC TEST

This section presents the outline functions and the detailed procedure of the measurement techniques and instrumentation required for determining the experimental natural frequencies and the mode shapes of the developed test models.

This test demonstrates the ability of space vehicle to withstand or, if appropriate, to operate in the design level vibration environment, which is the maximum level, imposed in flight plus a design margin.

Vibration shall be applied at the base of the adapter via fixture in each three orthogonal directions, one direction being parallel to the thrust axis. [Spanos, 1995]. Also transient response tested in this research by changing the load with variable time.

The vibration characteristics of the linear elastic structure (frequency and amplitude) can be described by means of the frequency response function. which may be expressed in terms of magnitude, real or imaginary parts and phase angle.

In this work, the two kinds of the testing methods: the steady state (pure sine or random) and the transient, had been used to measure the natural frequencies of the test structural model.

STRUCTURAL SUBSYSTEM

The full duplex deployment simulation results can be achieved between full-scale prototype and a proper scale model if a PI-Number is derived from the governing representative quantity [Schuning, 1977][NASA 1970].

The geometrical-similarity between the model and the prototype is achieved in this work.

The structural subsystem is responsible for construction of the (Beam, plates, tube) and joining them with (hinges, clamped) the structural subsystem consists of the following items are shown in **Fig. (1).** And **Table (1).** Shown the materials and dimensions of different parts. Structural parts designed to remain rigid.

The experimental data stet represented the characteristics of one continuous structure, which was manufactured and assembled with certain tolerances and tested under certain environmental conditions.

Electrical motor of (3 rpm) is using to rotating the structure along the test, to simulate the satellite spinning. It's jointed to the structure at two positions in tube at medium and lower plates by two bolts in each position.

MATHEMATICAL MODEL FOR EXPERIMENTAL WORK

In this work the general equation of the model were used for calculating the strain, stress, vibration and all other deployment parameters. The strain is recorded by strain gage and analyzed using mathematical model developed from system characteristics. In this mathematical model, all static parameters were related directly to the strain.

The dynamic characteristics at deployment were measured in two methods by frequency response and transient response. To build the complete mathematical model for experimental calculations many parameters affecting operation have been considered as follows:

Static Load

The equivalent torque *Te* is given by

$$Te = Tg + Ts + Taer. + Tmag.$$

Where:

Tg = gravitational torque
Ts = solar pressure torque
Tare. = aerodynamic torque
Tmag. = magnetism torque

The total torque is less than one Newton per meter. The torque (1 N.m) is subjected to all parts of structure.

The force that applied to the structure from thruster load is 10N, where subject to the structure in vertical and horizontal direction.

Dynamic load

The loads that applied to the structure are variable with time at transient analysis and depend on the change of satellite position in space during rotation about earth, where effects the solar pressure and geomagnetic are changed.

In the frequency response analysis, the forces depend on the variable of frequency was effects on the structure were subject the structure to the range of frequency (0-25 Hz) depended on the theory analysis.

TEST MODELS

The experimental programme carried to investigate the static and dynamic behaviour .Two various test set-ups were used.

The first model is Static instrumentation as shown in **Fig. (2)** for measuring the strain of the structure at different parts.

The second model is Vibration instrumentation, for measuring the transient response and frequencies response of the structure at variable loads with time and variable frequencies.

The experimental apparatus used for the measurement of the free resonant frequencies and mode shapes, of the developed structure model, is shown schematically in **Fig. (3)**.

TEST PROCEDURE AND EXPERIMENTAL RESULTS

The objective of this section is to give a test procedure adopted to give accurate values of the strain, stress, natural frequencies of the prepared structure model. The procedure required that the structure, under test, be excited by a loads and the response at various points be measured.

In order that all test results may be compared meaningfully, the test procedure must establish homogeneous conditions throughout all stages of the work. Thus, the method used for supporting the structure, during each turn of the experiment, should be simple to set up and reproducible.

STATIC TEST

The first case is the test by the torque activated by weight attached to beam and joined with the structure by bolts. The change of the weight gives the variable torques at deployment.

Strains are recorded and Von stresses computed in the same manner as for static analysis. **Fig. (4)** shows the strain & stress at different positions when the structure is subjected to a torque (1N.m).

Second case is activated by weight attached directly to the structure to represent the thruster force in horizontal and vertical directions; the strain gauges are connected to all parts of structure.

Fig. (5) shows the strain and Von misses stresses at different positions in horizontal & vertical directions of structure when the structure is subjected to the thrust load (10N) in X-direction.

Fig. (6) shows the strain and Von misses stresses at different positions in horizontal & vertical directions when the structure is subjected to the thrust load (10N) in Y-direction.

DYNAMIC TEST

The objective of this section is to introduce a test procedure adopted to give accurate values of the natural frequencies of the prepared structural model. The procedure required that the structure, under test, be excited by a force and the response at various points be measured. In order that all test results may be compared meaningfully, the test procedure must establish homogeneous conditions throughout all stages of the work. Thus the method used for hinged structure, during each turn of the experiment

An arbitrary choice of the point of excitation could lead to difficulties in producing the resonant condition. Exciting the structure at a nodal point (where the vibration amplitude vanishes) would result in missing out the peak in the inertance plot (magnitude or imaginary Vs frequency).

At first, the test was carried out to verify the spectrum plot, imposed by transient excitation (Impulse force) at location and two different positions in (upper, medium, lower and side plane) of the response accelerometer. The entrance (magnitude and force excited) of selected positions on the upper and side plane of structure, as varied within a selected time as shown in **Fig. (7).** It is clear that the acceleration is at time impulse domain and to be vanished after removed the load excitation.

Second, Using the steady state method (random excitation), the shaker decoupler and the accelerometer had been chosen to be at location in (upper, medium, lower and side plane). The test by this manner was made for a frequency range (0-25Hz) and the inertance plots (absolute magnitude, imaginary) had been acquired, as shown in figures (8-A, B, C, and D). It is clear at all positions that be tested is the some of shape and small different in value in some parts but they are different with other parts.

RESULTS AND DISCUSSION

From the stress levels at subjected torque (1N.m) at deployment configuration the upper plate suffers higher stress levels than another plates and beams. The critical areas were at hinge position; a (15) N/cm^2 stress was detected for Von misses stresses, a level of (-3.5) N/cm^2 was observed at side plate.

When the structure is subjected to thruster force in x-coordinate, maximum stress occurs at the medium plat is (146) N/cm^2 and minimum at upper plate is (-49) N/cm^2.

When the structure is subjected to thruster load in y-coordinate, max. Stresses occur at side plane is (34) N/cm^2 and min. at bar is (-8) N/cm

The stresses distribution in horizontal and vertical direction, is different when the structure is subjected to (1N.m) the stresses from edge increases in horizontal-direction to mid plate, and return to the same shape in the other side, Such as sine shape. But in the vertical-direction the stresses is increased exponentially from bottom to top of structure.

When the structure is subjected to the thruster load in horizontal coordinate the stresses in the horizontal-direction takes the sine shape. But in vertical-direction the curve decreases exponentially from bottom to top of structure.

When the structure is subjected to the thruster load in vertical coordinate the stresses in the horizontal-direction is the curve take approximate linearly.

When the structure is subjected to the transient force, the value of acceleration shown on the upper and side plate of structure is equal to (0.7mm/s^2). The transient response in all structural parts is the same because it depends on the force excitation, mass and stiffness of structure.

When the structure is subjected to vibration excitation, the acceleration of structure increases and became max. At natural frequency of 12Hz, and decreases to zero.

CONCLUSIONS

Structural design does not only encompass materials selection and configuration but must also include analyses and verification testing as part of the process, with an increasing reliance being placed upon analytical methods as experience grows.

The max. Stress occurs on centre of upper plate when the structure subjected to 1N.m, and max. Stress occurs at centre of medium plate when the structure subjected to thruster load in x-direction. And when the structure subjected to the thruster load in y-direction, the max. Stress occurs at side plane. The main characteristics obtained are to estimate the strain and stress at different parts and positions on the structure.

When the structure is subjected to transient load, the acceleration is changed with the excitation period and to be vanished after removed the load excitation. This change is not clear at different damping ratios because the impulse domain is very short time.

When the satellite is subjected to vibration excitation the resonance occurs approximately at 12Hz, and acceleration decreases to zero after this frequency. This indicates that the effect of low frequency is very important, and the vibration test must be conducted with this small range.

It was found that the magnitude is the same at all points on the same element (upper plate, medium plate, lower plate and side plate), but it differs from that measured another elements.

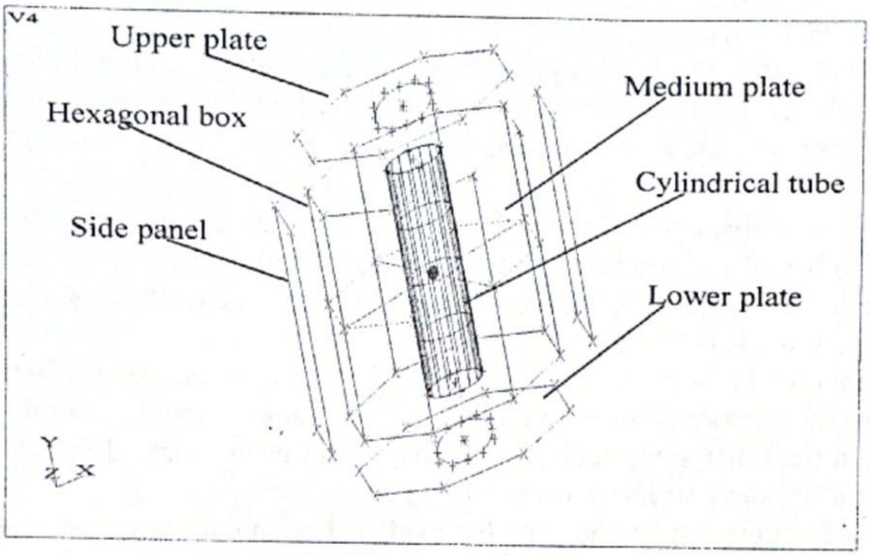


Fig. (1) Detailed design of the satellite structure

Table (1) The specimens used in the experimental tests.

Dimension			Properties						
			Length*width	t		E	G		y
Item	Material	Type	mm	mm	Kg/cm^2	Kg/cm^2	Kg/cm^2		Kg/cm^2
1	AL 7075.T6	Plate	275x275	1	2.82	700000	260000	0.33	5210
2	AL 7075.T6	Plate	110x215	1	2.82	700000	260000	0.33	5210
3	AL 2012	Beam	15x15x110	1	2.82	700000	260000	0.33	4410
4	AL 2021	Tube	78x215	1	2.82	700000	260000	0.33	4410

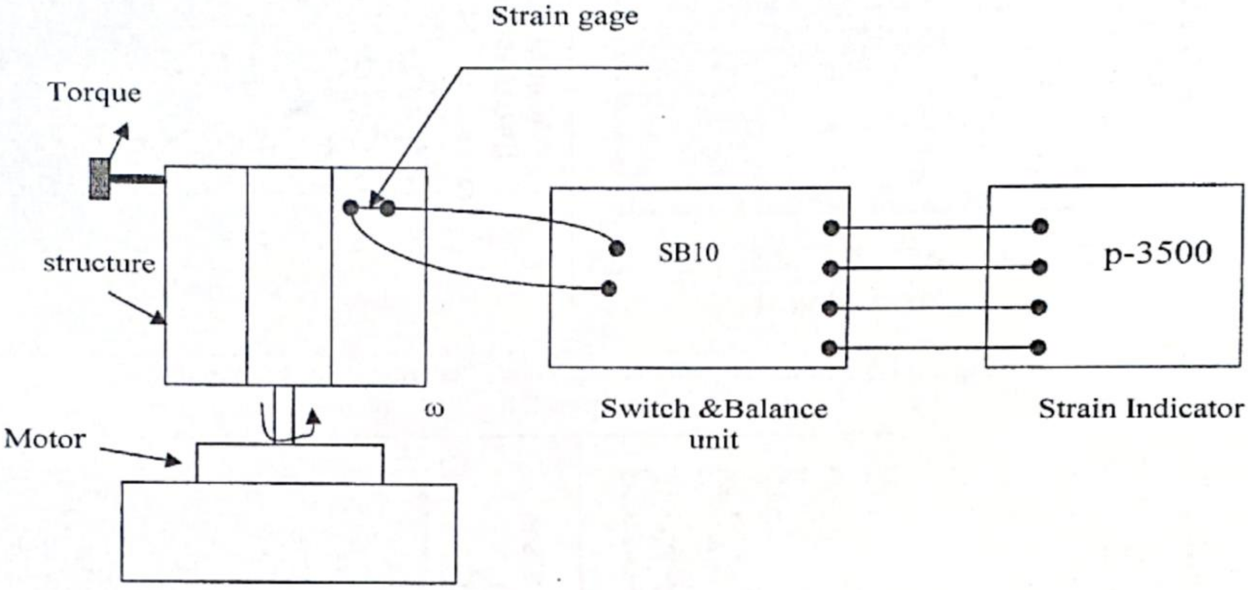


Fig. (2) The test setup for the static measurement

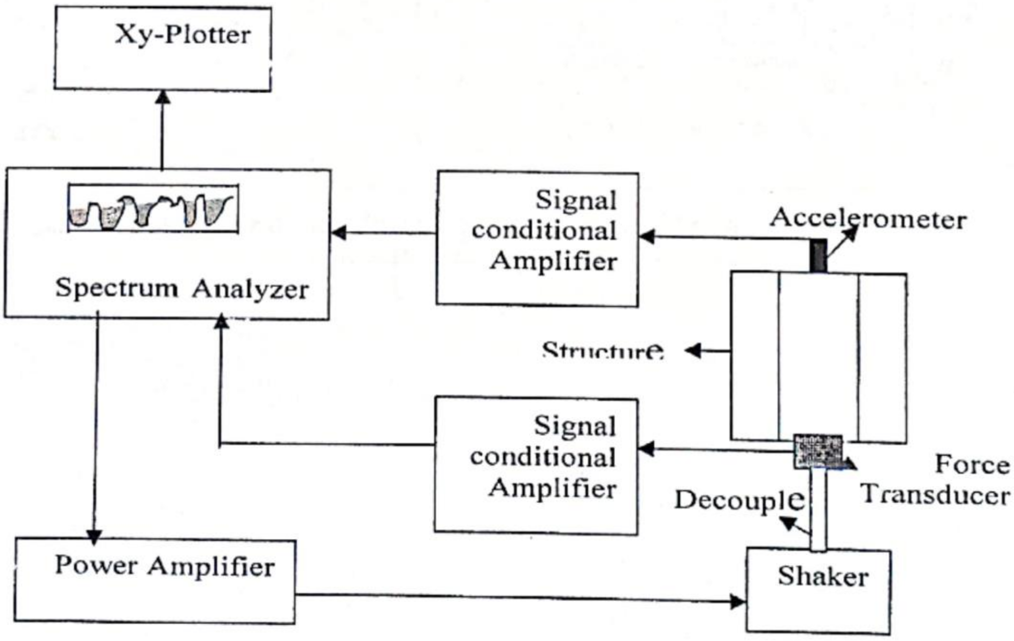
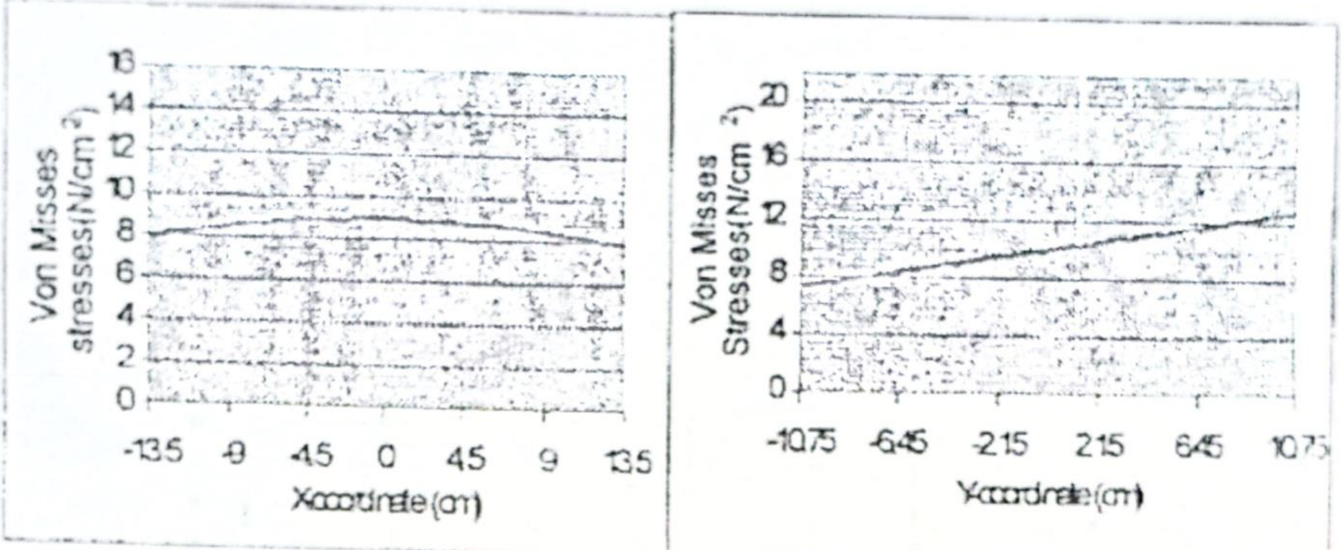
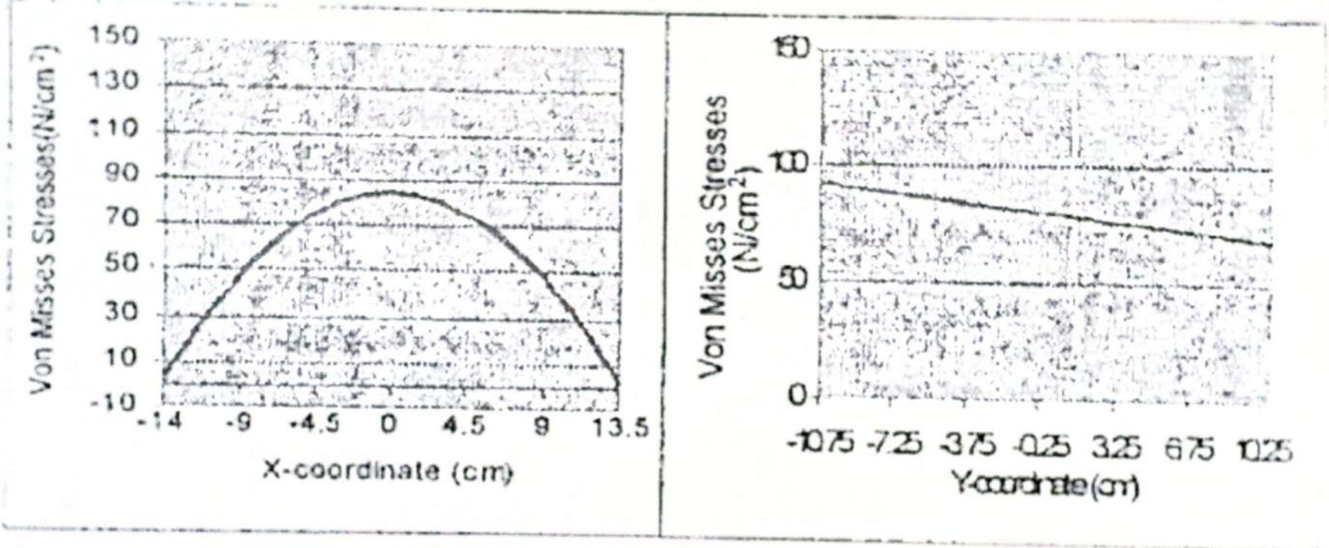


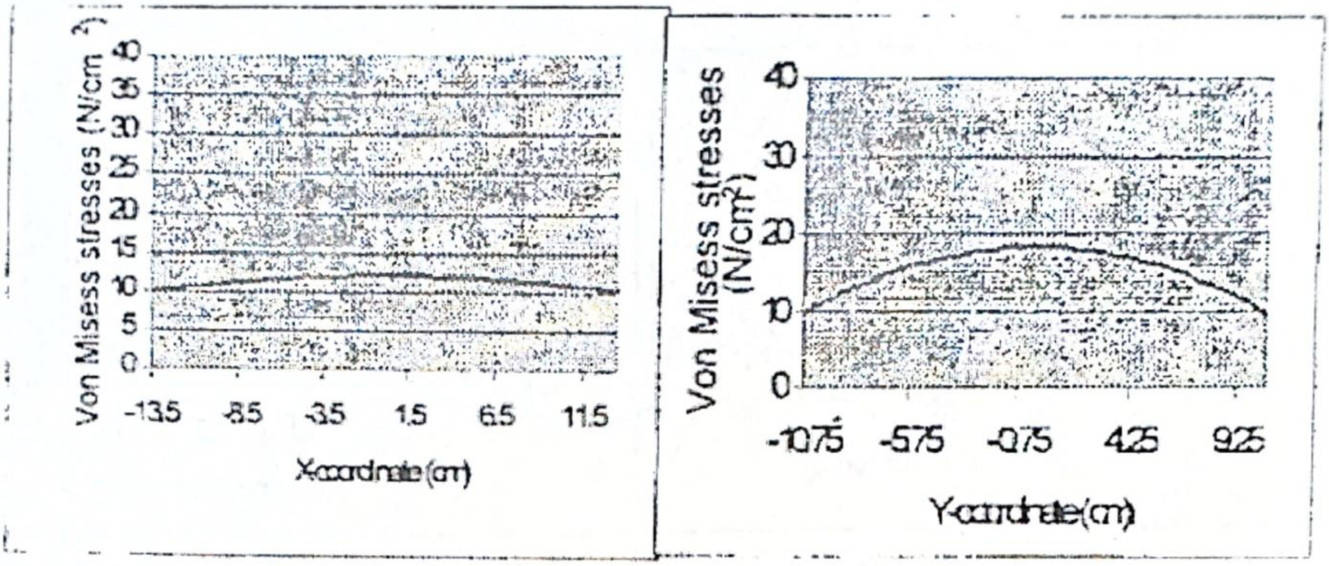
Fig. (3)Block diagram of the testing instrumentation and apparatus applied for the steady-state and transient methods.



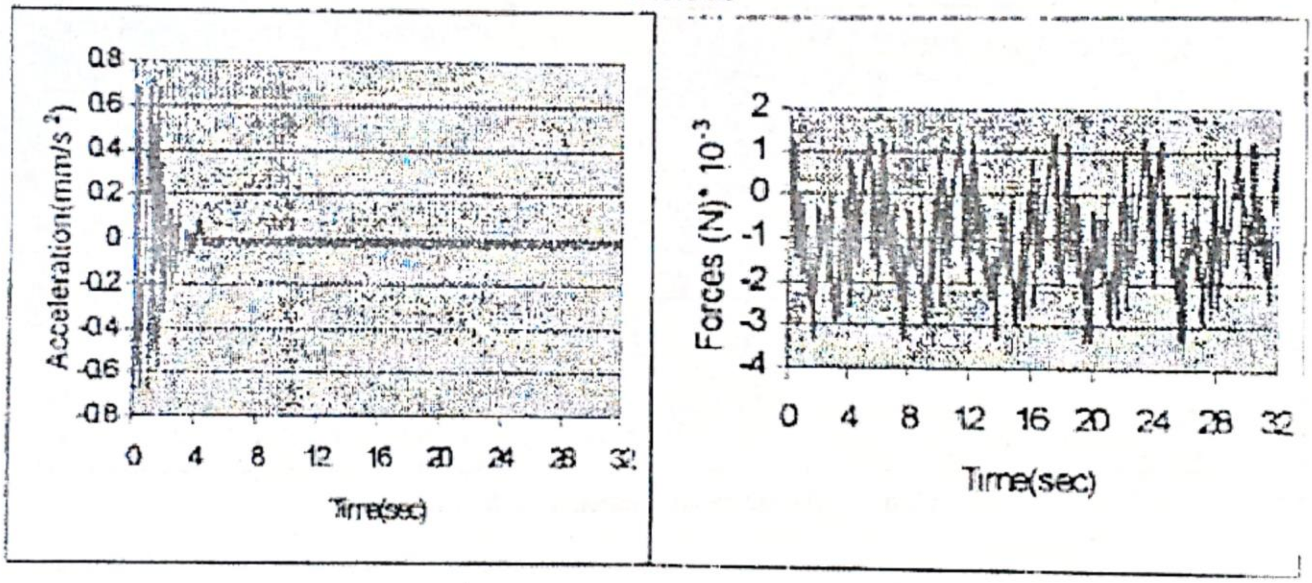
Figure(4)Von Misses stress along X and Y coordinate at subjected to torque (1N)



Figure(5)Von Misses stress along X and Y coordinate at thrusts load subjected in X direction



Figure(6)Von Misses stress along X and Y coordinate at thrusts load subjected in Y direction



Figure(7)Transient Response and excitation force for structure

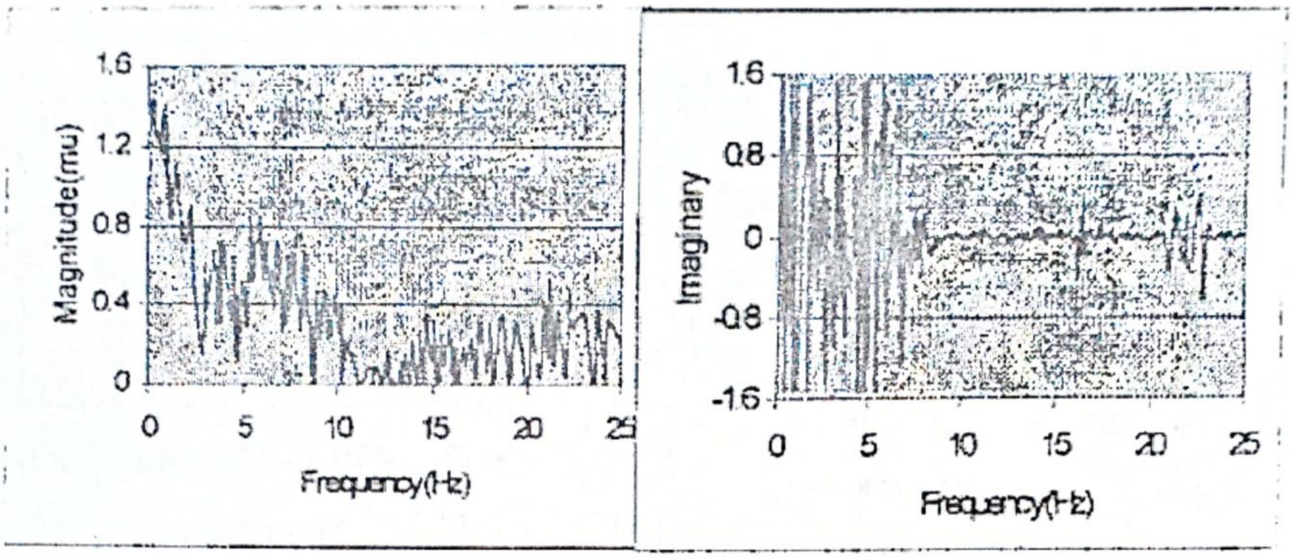
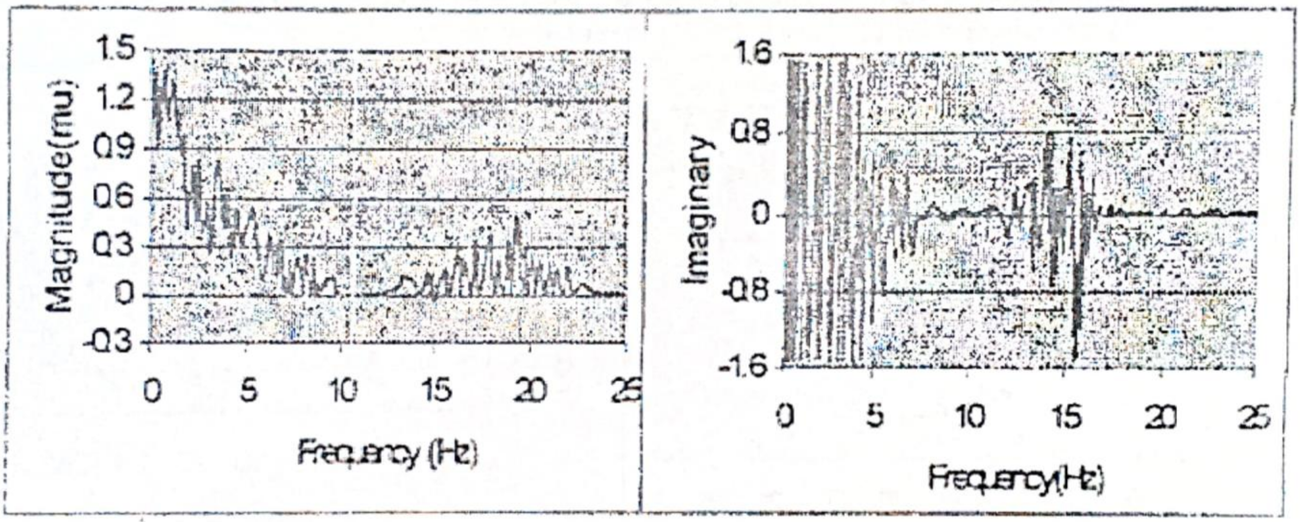
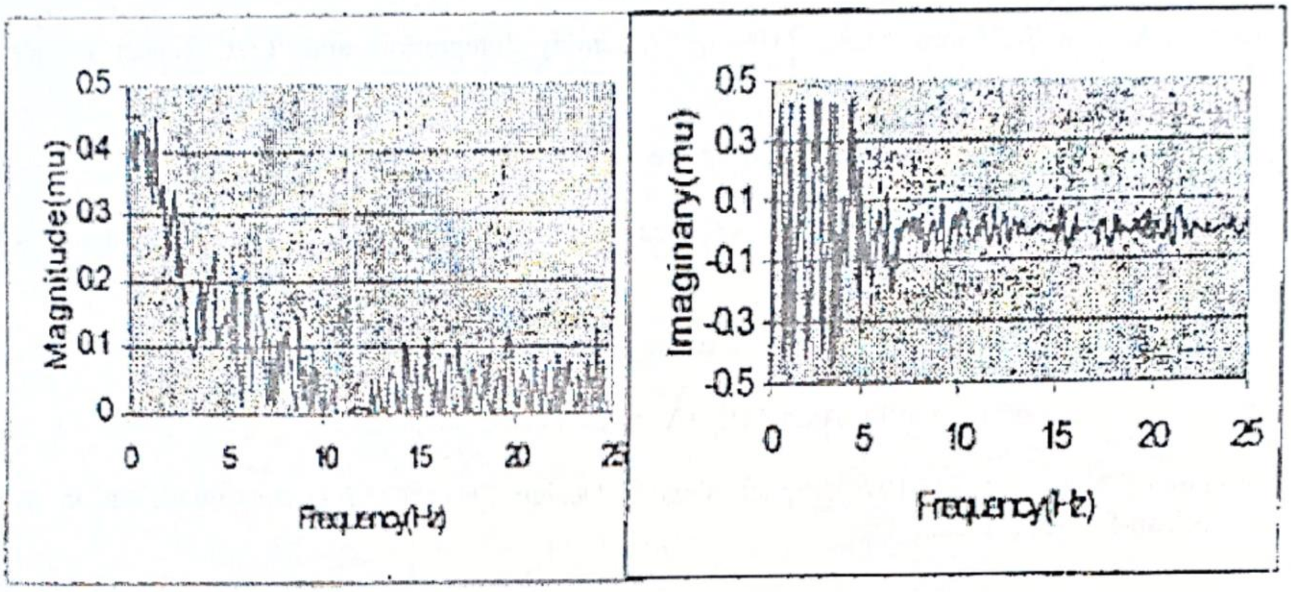


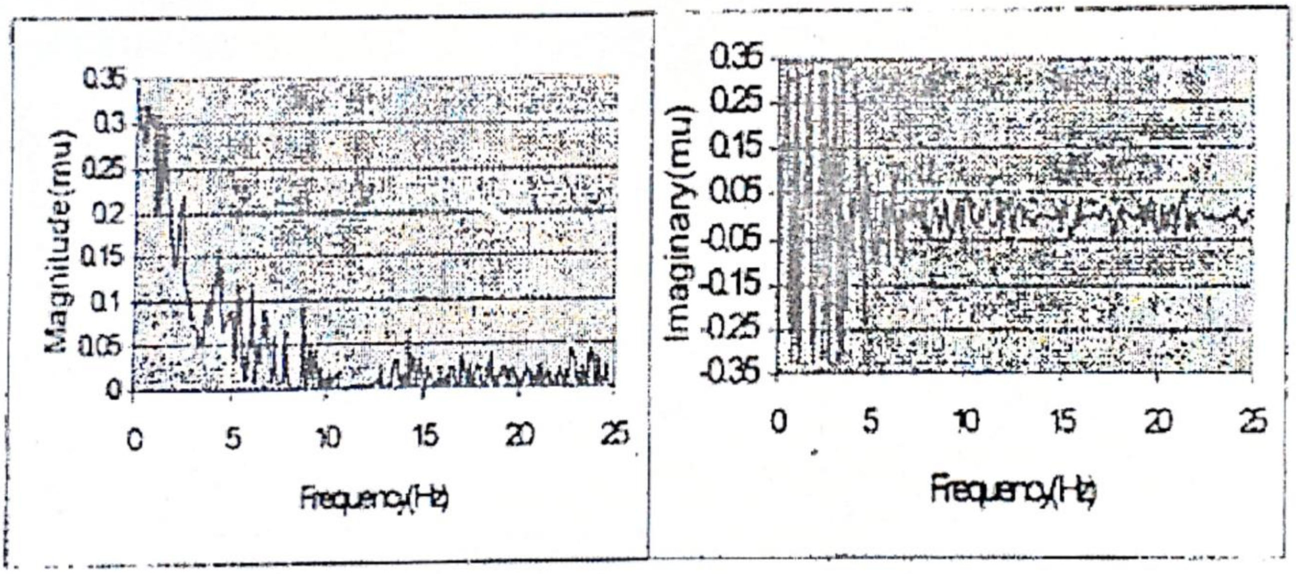
Figure (8-A) Frequency Response of the upper plate



Figure(8-B)Frequency Response of the side plane



Figure(8-C)Frequency Response of the medium plate



Figure(8-D)Frequency Response of the lower plate

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