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Design and Analysis of Servo Housing Fixture to Improve the Dynamic Performance

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***Abstract**: Fixtures are used to mount the work-piece to perform the operation such as turning, milling or machining. Fixture designs are very important parameter to achieve the balancing while performing all the operation. Industry is facing an issue with the turning operation on the servo housing fixture and accuracy of the turning is not achieving as per the standard due to the instability in rotation. This unstable rotation is caused due to the unbalance in the servo housing mass. The purpose of this research is to optimize the fixture design and improvement in the dynamic performance by doing parametric changes in the existing design of fixture. Work piece mounted on the fixture will transfer the static and dynamic load on the fixture by the different operation on the work piece. Hence fixture is sensitive to the loading on the fixture due to which the stresses developed. These stresses in the fixture is predicted using the finite element method, where the Eigen frequencies and Eigen vector is predicted using the dynamic analysis. Stress gradient has been extracted from the modal analysis which gives the high strain density region. Optimization is done in such a way that the dynamic performance of the fixture improves as compare the existing design. Balancing in the fixture design is more important, any system generate more response if kept unbalanced. Using this methodology the balancing in the fixture design is analyzed using harmonics analysis. Purpose of this analysis is to reduce the response in the structure and to shift the first harmonic and second harmonics by great extent.*

Key words- Modal Analysis, FEA, Servo Housing Fixture, Frequency Response

1. Introduction

Research in fixtures design with considering the work-piece and the fixture elements is rigid for the design and kinematic analysis. In this thesis, optimization techniques to minimize the response is evaluated, such that the fixture will be well balance during turning operation. The turning forces and the clamping forces imposed on the work-piece and the fixture elements bring excitation on the fixture.

During any operation which are performed on work-piece should be properly clamped and positioned o the fixtures, then only guaranteed outcome from the work-piece such as machining with accurate tolerance, turning can be assured [1]. In addition to the machining or turning operation, fixtures are also used for the operation like welding, assembly or inspection [2], [3] and [4]. Fixture affect the cost of manufacturing process around 5-15 % is estimated in manufacturing cycle. Hence to reduce the lead time and improve the manufacturing outcome, fixture design need to improve which indirectly save the cost [5].

Meyer and Liou [6], completed the various research on the modelling of fixtures under the dynamic condition. Author has proposed the linear programming method to locate the optimal position of work-piece. Wang et al. [7] developed advanced method called as smart fixturing systems to streamline the clamping forces to achieve the less displacement of work-piece, Author utilized FEM method to determine the displacement. Quality in the balancing and stability is ensured only when the work-piece is accurately and rigidly positioned. In the past, little analysis work was devoted to the design of fixtures. With the recent development of new techniques, software, and numerical solution and theories, much changes can be expended beyond design and synthesis for locating points. Past research in optimization in fixtures could not handle supports not necessarily on a single plane. Use of faster and better optimization techniques and a comparative study of original and modified design were not employed in fixturing analysis. In this thesis, finite element analysis is used for evaluating the deformation, Eigen values, Eigen vector and response in fixture elements. Secondly, optimization procedures is adopted to minimize the response and shifting the Eigen frequencies to the higher harmonics.

Complete assembly of servo housing fixture is generated in CAD software (CATIA). Detail of servo housing fixture is shown in Figure 1.

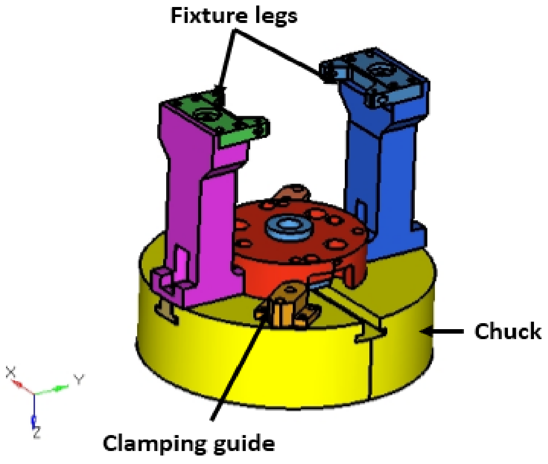

Figure 1: Servo Housing Fixture – 3D view

Scope of Work

In this work designing of the fixture which supports the servo housing machine is analyzed, while taking into consideration that its natural frequency does not occur in the excitation range of the fixture and turning excitation. Servo housing fixture are generally used for supporting automobile equipment which is used in automobiles. The fixture is designed such that its natural frequency does not fall under the frequency range of 16-50 Hz.

This thesis focused on the method of analyzing and optimizing a fixture design such that the weight of the fixture reduces with improvement in dynamic characteristic. With the nature of turning load and the complications on the geometry, both FEA (Finite Element) and optimization of fixture measures are dynamic in nature; also, to ensure the dynamic stability i.e. balancing while rotation is ensured from the response calculation. The modified fixture has been designed to shift the harmonics away from the existing design with less amplitude of response at the fixture.

2. Methodology

2.1. Material properties

The material for the analysis is specified by Company (Seimumero Nirman Pvt Ltd.). The material considered for the analysis is mild steel i.e. the jig and fixture assembly is made of mild steel. The entire component is assigned with relevantly density. The relevant material properties are summarized in Table 1.

Material property strain at rupture is greater than 25% for this fixture. Hence ductile phenomenon for the stress evaluation is considered for the analysis.

Table 1: Material Properties

Component	Servo Housing Fixture
Material	Steel
E-modulus [MPa]	2,03,000
Poisson Ration	0.3
Density [kg/m^3]	7800
Yield limit [MPa]	285
Ultimate Limit	360

2.2. Modelling strategy

All individual jig and fixtures components (Legs and chuck) are meshed with 3D solid (Tet10) element. Bolted joints are considered to be stiff and hence modelled using a beam and RBE2 connection. Bolts are modelled using rigid element and beam elements. The detail FE mesh is shown in Figure 2.

Servo housing is modelled as lumped mass and its weight is distributed to the fixture mounting location using rigid element named as RBE2. Mass moment of inertia for servo housing is calculated considering the cylinder dimensions. The diameter of beam element is equal to that of bolt with high material stiffness 100 time higher than the normal steel stiffness. No load in case of dynamic analysis as it is free-free modal analysis.

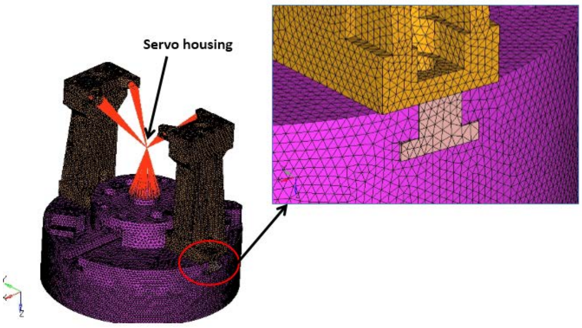

Figure 2: Servo Housing Fixture – 3D View

For the boundary condition, fixture base is constraint in vertical direction. Mass moment of inertia is assigned for the servo housing in order to define the rotational effect of servo housing for the dynamic analysis.

Total force of magnitude 1000N is applied on the unbalance mass COG of fixture at tangential direction. Force is applied in tangential direction as force due to turning will be tangential in direction. This load is vary from 500 -4000 Hz.

Mass and FE modelling strategy is described in detail in Table 2

Table 2: Mass and FE details

Components	Total Mass [kg]	FE detail
Servo Housing	12.7	Lumped Mass
Fixture	79	FE mesh
Total	90.7	

3. Result and Discussion

Modal analysis is performed to assess the Eigen frequencies, Eigen vector of the servo housing fixture. By performing the modal analysis eigenvalues and eigenvector are accurately extracted which are presented in Table 3 and highlighted as dark color.

- First mode of servo housing fixture is observed at 761 Hz which is far away from the excitation range (16-50 Hz). First mode is the lateral bending of the leg of the servo housing fixture. Detail mode shape is shown in Figure 3. No local mode has been observed for this analysis as no small component are attached to the fixture assembly.
- Second mode of servo housing fixture is observed at 1338 Hz which is far away from the excitation range. Second mode is the torsional mode of the servo housing fixture. Detail of the plot is shown in Figure 4.
- Third mode of servo housing fixture is observed at 1431 Hz which is far away from the excitation range. Third mode is the longitudinal mode of the servo housing fixture in which the legs are participating the maximum modal mass. Detail of the plot is shown in Figure 5.

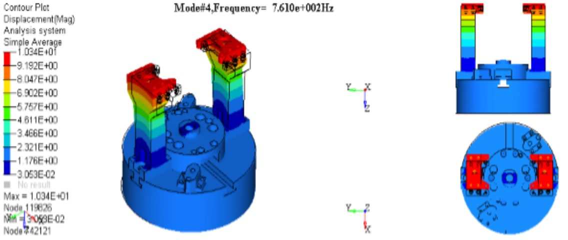

Figure 3: First mode @ 761 Hz; lateral bending mode

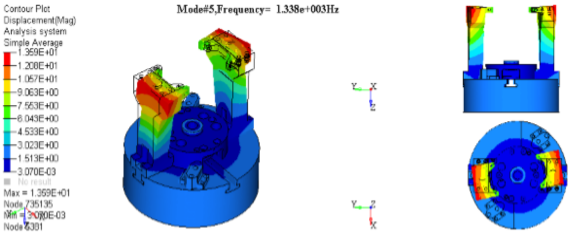

Figure 4: Second mode @ 1338 Hz; Torsional mode

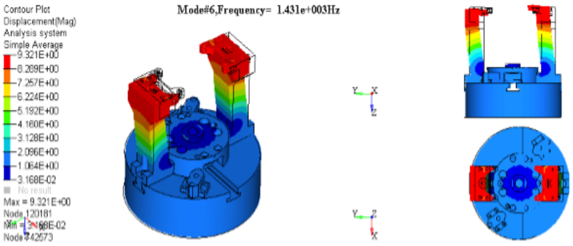

Figure 5: Third mode @ 1431 Hz; 1st longitudinal bending mode

Table 3: Eigen Values - Original Design

Mode	Frequency [Hz]	Mode shape
1	3527	Torsional mode
2	4322	Lateral Bending mode
3	4347	Longitudinal Bending mode

Stress or Strain gradient provide the overall idea of high strain and low strain region. Region with high strain mean it need additional strength or stiffness, whereas low strain means material can be removed from that region

High stress gradient has been observed at the foot of the leg, whereas there is no gradient at the top of the leg. This mean that the leg of the fixture can be optimized but with improvement in strength at the bottom of the leg. This is achieved by adding the ribs at the side of the legs which is discussed in later section.

Similarly there is no strain gradient is observed at the chuck and material can be removed from the chuck with keeping in mind the balancing of servo housing fixture system. Material is removed in such a way that the unbalance in servo housing can be compensate and more balancing is achieved. Details of the stress gradient is shown in Figure 6.

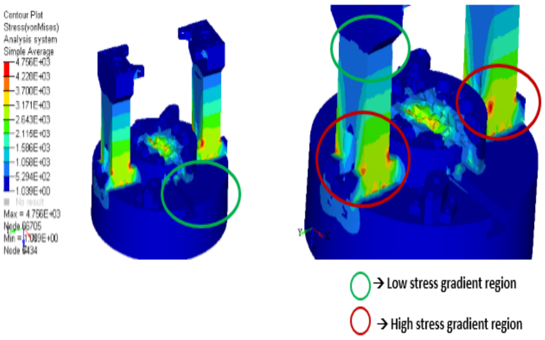

Figure 6: Stress gradient at first harmonics

After the modification the Eigen value and vectors are as follows

Global modes and their and corresponding mode shape are observed at following frequencies

- @766 Hz; Lateral bending of servo housing fixture

- @1311 Hz; Torsional bending of servo housing fixture
- @1498 Hz; 1st Longitudinal bending of servo housing fixture
- @3403 Hz; 2nd Longitudinal bending of servo housing fixture
- @3798 HZ; 3rd Longitudinal bending of servo housing fixture

In Table 4 first three harmonics for the modified design is tabulated along with the original design and deviation between them is calculated.

To reduce the vibration modification in servo housing fixture has been done. The modified CAD model for servo housing fixture is shown in the Figure 7. Dimension for the rib is shown in Figure 8.

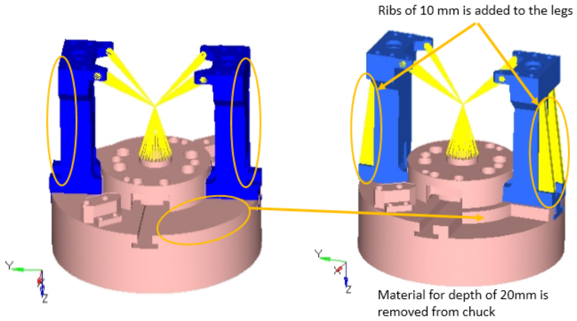

Figure 7: Modified Model for Servo housing Fixture

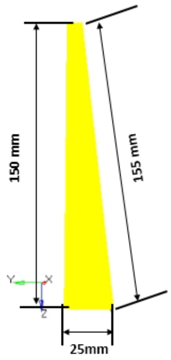

Figure 8: Rib dimension

Table 4: Eigen value for Original and modified design

Frequency – Original Design [Hz]	Frequency – Modified Design [Hz]	Variation (%)
761	766	0.7
1338	1311	-2.01
1431	1498	4.68

FRF comparison

After calculation of amplitude for the original design, frequency response analysis with the same set-up is performed on the modified design. Purpose of the modified design is to reduce the vibration amplitude of the fixture system shifting the frequency obtain from the modal analysis. From the graph it is observed that the response at first harmonic is completely disappeared. This is the good indication of fixture system balancing.

From the result obtained for leg1, it can say that the vibration amplitude at the leg1 is reduced by 50% as compared to the original design. This indicates improvement in the dynamic performance. Amplitude is reduced from 1.6 to 0.8 for second harmonics and 2.25 to 0.4 for third harmonics i.e. 82% reduction in the response. Detail is shown in Figure 9

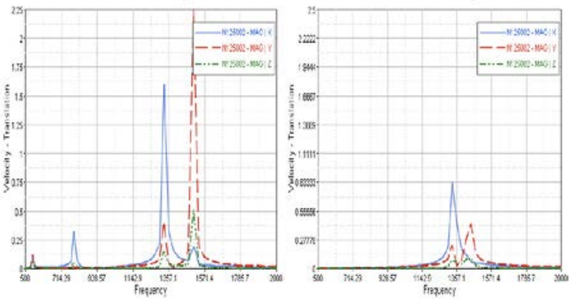

Figure 9: Vibration amplitude (mm/s): Comparison – Leg1

From the result obtained for leg2, it can say that the vibration amplitude at the leg2 is reduced by 54% as compared to the original design. This indicates improvement in the dynamic performance. Amplitude is reduced from 1.76 to 0.8 for second harmonics and 2.25 to 0.42 for third harmonics i.e. 81% reduction in the response. Detail is shown in Figure 10.

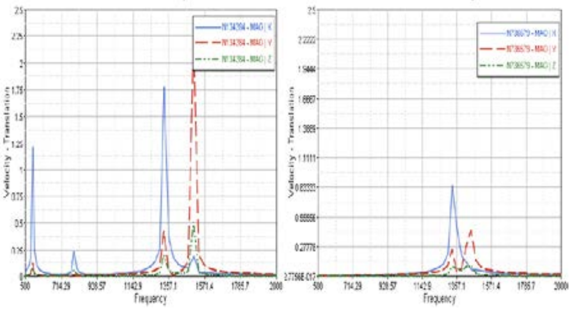

Figure 10: Vibration amplitude (mm/s): Comparison – Leg2

From the result obtained for chuck, it can say that the vibration amplitude at the chuck is reduced by 67% as compared to the original design. This indicates improvement in the dynamic performance. Amplitude is reduced from 0.28 to 0.09 for second harmonics and 0.45 to 0.08 for third harmonics i.e. 82% reduction in the response. Detail is shown in Figure 11.

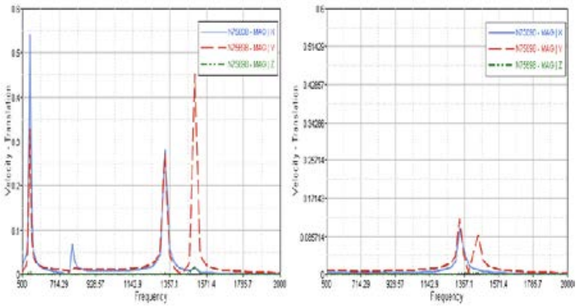

Figure 11: Vibration amplitude (mm/s): Comparison - Chuck

Conclusion

Modal analysis of original design is performed and strain energy or stress gradient is extracted which help to locate the region of high stiffness and low stiffness. Material from high stiff region has been removed and similarly material at low stiff region is added, later of modification the weight of fixture assembly is reduced to 90.2 kg as compared to the 90.7 kg in the original design. It has been observed that the Eigen frequencies has increased as compared to the original design, Due to modification in the leg and chuck of the structure the first natural frequency is appeared at 766 Hz which is slightly more than the first global mode of original design.

Reduction in the frequency is also observed for other global modes but the variation is less than 1%. First longitudinal mode of the fixture is observed at third harmonics which will be the mostly excited mode during vibration, the frequency at this mode is shifted higher by 4.6%. Hence the purpose of modification in the design is still valid.

Shifting Eigen value to higher be not alone can give the confidence of improvement. Hence response analysis is performed to evaluate the response in term of velocity on fixture. Result of response analysis is showing peak at same frequencies as obtained in modal analysis. This give validation of result obtained from the Modal analysis. From the result obtained it can say that the vibration amplitude at the fixture system is reduced by at least 50% as compared to the original design. This indicates improvement in the dynamic performance. Hence this will improve the stability of fixture during turning operation.

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