Study of Fuel Consumption Meter Advanced (FCMA) Using Mechanical Exciter Machine

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Abstract- *The main objective of this paper is to present the design of Mechanical Exciter Machine for study of effect of vibration generation during transportation on Fuel Consumption Meter Advanced i.e. FCMA. This study is require because the Load Cell in FCMA gets damage due to unwanted vibration produce during transportation. To study the effects of these vibration generation on FCMA, Exciter Machine is needful. In this paper, design and development of the Mechanical Exciter Machine for FCMA have been completed. This paper gives the design procedure of Mechanical Exciter Machine components by mathematical calculations. To fix the FCMA on the Mechanical Exciter Machine, Fixture Table is required and it is also designed by considering the natural frequencies of it computed by FEA software. Design of Fixture Table is require to avoid resonance during the working of Mechanical Exciter Machine. For all 3D modeling purpose, SOLID EDGE ST2 software has been used. Modal Analysis and Harmonic Analysis have done by FEA software i.e. ANSYS WORKBENCH 15.0. To drive the motor of Mechanical Exciter Machine at different frequencies, Variable Frequency Drive (VFD) has been used. In the experimentation, readings of vibration amplitude have been taken with the help of contact type vibration amplitude measuring device. After experimentation, the experimental results has been correlated with the results of Harmonic Analysis.*

Keywords- Mechanical Exciter Machine, FCMA, Finite Element Analysis, Fixture Table Design, Load Cell, Variable Frequency Drive.

I. INTRODUCTION

FCMA is an instrument which is generally used for calculating fuel consumption of the engine during testing. It is a type of smart and speedy fuel consumption meter which gives experimentally actual value of fuel consumed by the engine while testing. It is the gravimetric type Fuel Consumption Meter based up on principle of weight and adopted the concept of instantaneous flow measuring. For weight measuring purpose single point Load Cell sensor is used. One end of the Load Cell is fix to the cast iron bed present in FCMA and at other end oil container is fixed with the help of bolting. As oil container filled with the fuel used for engine testing, it measures the weight of fuel. The change in the weight of the fuel present in the oil container is measured by this Load Cell. By using this change in weight process, instrument automatically calculate the fuel consumption rate for that particular time period. But during the transportation, Load Cell gets damage due to unwanted vibrations generated. Load cell measures only vertical direction displacement. So, if vertical directional vibrations generated with high amplitude, Load Cell gets damage. After Load Cell getting damage, obviously Fuel Consumption Meter cannot work properly. So, for experimental study of effects of vibration on FCMA, Exciter Machine required.

There are various types of Exciter Machines are available in the market but it's been found that to design and develop Mechanical Exciter Machine at own place and with available material will be a best option. For this purpose, simple procedure have been followed i.e. it should be simple in design, compact in size and having less for manufacturing cost. The main components required to develop Mechanical Exciter Machine are

1. Base Frame
2. Drive System (Vibro Motor)
3. Motor Support Plate
4. Fixture Table
5. Helical Compression Springs
6. Spring Support Rods

So, to study the effects of vibration by using developed Mechanical Exciter Machine, testing performed on the FCMA with different frequencies to achieve experimentation goal.

Finite Element Analysis is very useful method to solve the engineering problem. ANSYS WORKBENCH 15.0 software has been used to carried out Finite Element Analysis.

II. LITERATURE REVIEW

Giovanni Boschetti, Roberto Caracciolo, Dario Richiedei and Alberto Trevisani [1] were present paper on the effects on vibrations on the Load Cell. According to this paper, Load Cell only sense the weight acting on the Load Cell in vertically downward direction. So, this paper gives information to focus on only vertical directional vibration amplitude generated in Load Cell.

According to Nitinkumar Anekar, V. V. Ruiwale, Shrikant Nimbalkar and Pramod Rao [2], simple and compact Mechanical Vibration Exciter Machine can be designed and manufactured by using vibratory motor. Vibratory motor has two unbalanced masses attached at two ends of a shaft of the motor. When motor shaft starts rotating. At the same time, unbalanced mass attached to the shaft starts rotating and produces centrifugal force. By using this centrifugal force, vibrations can be generated in the test specimen.

Aditya Pawar, Sumit Varje, Shubham Patil, Ashish Badade and Kamlesh Sasane [3] presented paper on the Mechanical Vibration Exciter. In their work exciter machine is made by using cam and follower mechanism. So, in this paper, alternative method to design and manufacture mechanical vibration exciter can be found.

A. V. Ramana Rao, CH. Bhau Prakash and G. H. Tammi Raju [6] presented paper on selection of vibratory motor for the particular application. They gives information to check the acceleration of machine by mathematical calculations.

Emmanuel Rodriguez [7] presented paper in which he gives the information about how to calculate theoretical stiffness of conical compression spring in his research paper. In this paper, they also gives the comparison of helical compression spring and conical type spring.

Yongchang Yu, Shuaijun Zhang, He Li, Xiaofei Wang and Yadong Tang [8] presented research paper, in which they have been performed modal and harmonic response analysis on components of Ditch device by using ANSYS software. On the basis of results. They have concluded that in which frequency range key components of Ditch Device have safe.

III. OBJECTIVE

Design and manufacture the Mechanical Exciter Machine for testing of FCMA which can operate appropriately for designed frequency range. Mechanical Exciter Machine should be simple in design, compact in size and having less for manufacturing cost. Final target is to do experimental study of harmful effects of vibration on FCMA.

IV. METHODOLOGY

Methodology is very crucial because it gives correct direction for completing the work on time. For completion of this experiment, below explained methodology can be followed. First specify the problem statement. Do the Literature Survey on problem statement. Then, the calculations of required parts of Mechanical Exciter Machine e.g. Fixture Table, Motor selection and Helical Compression Spring. Then 3D modeling of necessary parts for analysis purpose in SOLID EDGE ST2 software. Then use FEA software e.g. ANSYS WORKBENCH 15.0 for Modal Analysis of Fixture Table and FCMA and Harmonic Analysis of FCMA. After getting FEA Results, confirm with experiment results.

V. DESIGN CALCULATION

A. Fixture Table Calculations

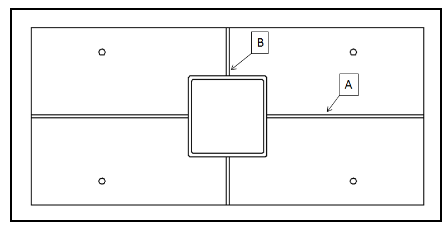

Fig. 1.Initial Design of Fixture Table.

To calculate the resonant frequency of the Fixture Table use formula as,

$$f = 4 \times 23.5 \times 10^4 \times \left(\frac{h}{b^2}\right) \times \lambda$$

Where, λ = mode constant & calculated by,

$$\lambda^2 = 0.39 + 0.96 \left(\frac{b}{l}\right)^2 + 0.36 \left(\frac{b}{l}\right)^4$$

by rearranging above equation.

$$h = \frac{f \times b^2}{4 \times 23.5 \times 10^4 \times \lambda}$$

For calculating minimum thickness of the top plate, take safe frequency as f = 1000 Hz & b = 27.3 (Diagonal length of top Plate from center)

consider, $\left(\frac{b}{l}\right) = 1$

Therefore, λ = 1.31

then,

$$h = \frac{1000 \times 27.3^2}{4 \times 23.5 \times 10^4 \times 1.31}$$

h = 0.605 cm

So, for the manufacturing purpose, take 8 mm thickness plate.

For, the side brace (A) of the fixture

b = 20 cm and l = 5.5 cm

$\left(\frac{b}{l}\right) = 3.63$

$\lambda = 8.69$

$h_A = \frac{1000 \times 20^2}{23.5 \times 10^4 \times 8.69} = 0.19$ cm

For the manufacturing ease, take 4 mm thickness plate for side brace (A)

Similarly,
For the side brace (B) of the fixture
b = 6 cm and l = 5.5 cm

$\left(\frac{b}{l}\right) = 1.09$

$\lambda = 1.42$

$h_B = \frac{1000 \times 6^2}{23.5 \times 10^4 \times 1.42} = 0.11$ cm

So for the manufacturing ease like welding, again take 4 mm thickness plate for side brace (B)

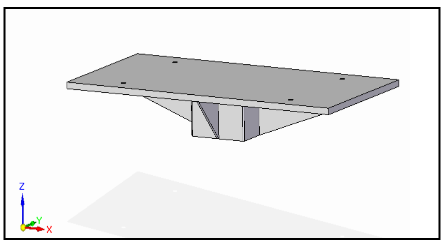

Fig. 2.CAD Model of Fixture Table.

Fig. 2. shows the CAD Model of Fixture Table. It is important part of the Mechanical Exciter Machine because it transmits the uniform vibrations form drive system to the test specimens uniformly. The maximum dimensions of fixture are 500 × 220 in mm for top plate surface. Height of fixture is 63 mm.

B. Helical Spring Calculations

Total Weight on the 4 springs = 46 kg = 460 N
Maximum Force on each spring = 460/4 = 115 ≈ 120 N
For the design of spring, consider for fluctuating loading condition.
So,
$P_{min} = 120$ N and $P_{max} = 240$ N
C = 8 (For Industrial Purpose) & G = 81370 N/mm^2
- Calculations of Wire Diameter - d

$\tau_{max} = 0.3 \times S_{ut}$
$= 0.3 \times 1050$
$= 315$ MPa

Wahl's Factor

$K = \left(\frac{4C-1}{4C-4}\right) + \left(\frac{0.615}{C}\right)$
$= 1.184$

$\tau = K \left(\frac{8 \times P_{max} \times C}{\pi \times d^2}\right)$

$315 = \frac{1.184 \times 8 \times 240 \times 8}{\pi \times d^2}$

$d^2 = 18.37$,

$d = 4.28 \approx 4.5$ mm

- Now, Mean Coil Diameter

$D = C \times d = 36$ mm

- Number of Active Turns (N)

$\delta = \left(\frac{8 \times (P_{max} - P_{min}) \times D^3 \times N}{G \times d^4}\right)$

Consider, $\delta = 10$ mm

$10 = \frac{8 \times (240 - 120) \times 36^3 \times N}{81370 \times (4.5)^4}$

$N = 7.45 \approx 8$

- For square and ground end style of spring number of inactive coils are 2.

$N_t = 8 + 2 = 10$ Coils.

- Therefore, Solid Length of Spring = $N_t \times d$
= 45 mm

- Free Length of The Spring

The actual deflection of spring under a maximum force 240 N.

$\delta_{act} = \frac{8 \times 240 \times 36^3 \times 8}{81370 \times 4.5^4} = 21.47$ mm

It is assumed that when spring is subjected to maximum force there will be gap of 1 mm between two consecutive coils. Therefore,

Total Axial Gap $= (N_t - 1) \times$ Gap = 9 mm
Therefore, Total free length of the spring
= Solid length + Total Axial Gap + δ_{act} = 75.47 mm

- Pitch of Coil $= \frac{\text{Free Length}}{(N_t - 1)} = 7.88$ mm

C. To check final acceleration of Mechanical Exciter Machine

Information known:-

F_v = Centrifugal Force of Vibro Motor = 1940 N
As here only one motor is used,
$F_t = F_v \times 1 = 1940$ N = 197.76 kg
Total Weight to excite = W_t = 46 kg

Therefore,

Acceleration $a = \frac{F_t}{W_t} = \frac{197.76}{46} = 4.29$

For actual condition, consider 95% efficiency of Motor

$a = 4.29 \times 0.95 = 4.07\ G \approx 4\ G$

So, the acceleration of total machine is 4G.

Fig. 3.Drive System (Vibro Motor).

VI. FINITE ELEMENT ANALYSIS

In this case, Finite Element Analysis have been done by using ANSYS WORKBENCH 15.0 Software. In this work, Modal Analysis and Harmonic Response Analysis have been carried out.

A. Modal Analysis of Fixture Table

For the modal analysis, use the 'Fixed Support' as constraint equation at bottom part of the fixture.

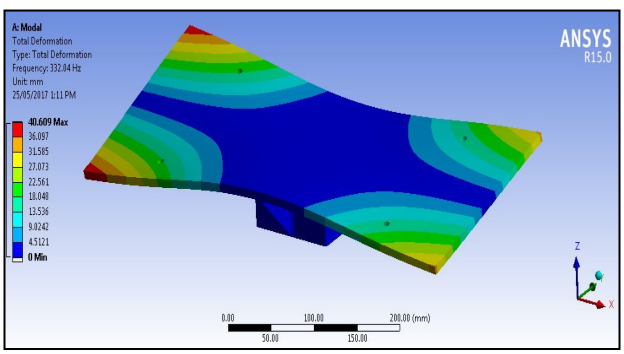

Fig. 4.Maximum Deformation at 2nd Mode of Vibration.

After calculating all natural frequency by software it is observed that the maximum deformation 40.609 mm occurs at 2nd natural frequency.

B. Modal Analysis of FCMA

For the modal analysis of FCMA, use the 'Fixed Support' as constraint equation at bottom part of the FCMA.

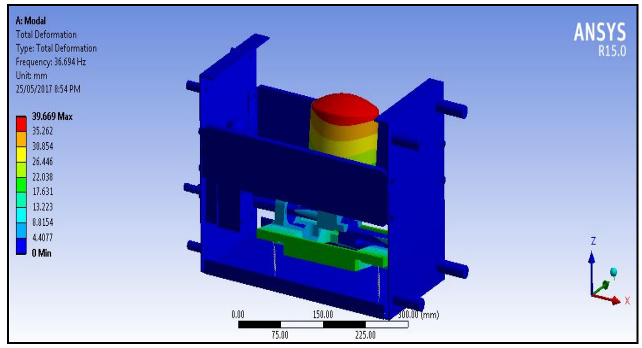

Fig. 5.Maximum Deformation at 3rd Mode of Vibration.

In above Fig. 10, it is seen that the maximum deformation occurs at 3rd natural frequency of FCMA i.e. 39.669 mm.

C. Harmonic Analysis of Test Specimen (FCMA)

For the Harmonic Analysis of FCMA, use same meshing type and size as used earlier for modal analysis.

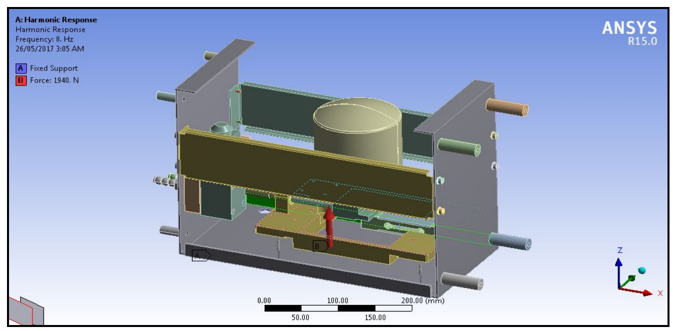

Fig. 6.Boundary conditions for the Harmonic Analysis of FCMA.

Boundary conditions for Harmonic Analysis are important. For Harmonic Analysis, fixed the 4 holes presented at the bottom side of the carriage of FCMA and apply the 1940 N force in vertically upward direction. 20-30 Hz frequency range for Harmonic Analysis have been used.

VII. EXPERIMENTAL SETUP

Experimentation is required to check the response of the Mechanical Exciter Machine and also to study the harmful effects of vibrations in the test specimen practically. FCMA is fixed on the Fixture Table by using 4 bolts. As drive system is a motor, 3 phase A.C. supply is required to run the motor.

Fig. 7.Variable Frequency Drive (VFD).

To set the frequency of the vibration one device is used called as Variable Frequency Drive (VFD). Frequency value is directly show on the LED display of VFD.

Fig. 8.Vibration Meter.

To measure the vibration amplitude for particular frequency value, use vibration measurement device called Vibration Meter.

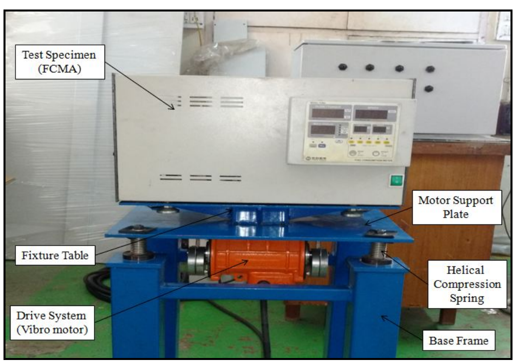

Fig. 9.Actual Test Setup in Lab.

Procedure for testing is very simple. First fix the test specimen on the Fixture Table. Make sure that test specimen is fixed properly by fasteners or clamping plates. Fix the probe of vibration meter at the location, where vibration amplitude is to be measured. Then turn on the 3 phase A.C. supply. Set the frequency with the help of Variable Frequency Drive. Take the readings of vibration amplitude (mm) values for different frequency value. For the experimental analysis, use the general frequency range which is considered for the vibration generation during transportation i.e. 20-30 Hz.

VIII. RESULTS AND DISCUSSION

As selected motor having maximum frequency of 50 Hz. So, Developed Mechanical Exciter Machine generates vibrations up to 50 Hz.

A. Modal Analysis of Fixture Table

From the Modal Analysis of Fixture Table, first natural frequency occur at 329 Hz. This frequency is much greater than the maximum working frequency of the Mechanical Exciter Machine 50 Hz. So, there will not resonance occur in Fixture Table under working frequency range.

Table I .Modal Analysis Of Fixture Table

Mode No.	Natural Frequency (Hz)	Maximum Deformation (mm)
1	329.29	40.397
2	332.04	40.609
3	384.97	31.182
4	415.26	32.778
5	791.48	20.957
6	979.19	34.461
7	997.55	34.656

Table I shows, the natural frequencies of Fixture Table and their respective deformation values. From this table, it is observed that maximum deformation 40.609 mm occurs at 2nd natural frequency 332.04 Hz.

B. Modal Analysis of FCMA

All the natural frequencies of FCMA are under the range of Exciter Machine i.e. 0-50 Hz. So, by using this Mechanical Exciter Machine can perform vibration analysis on FCMA easily.

Table II. Modal Analysis Of Fcma

Mode No.	Natural Frequency (Hz)	Maximum Deformation (mm)
1	11.361	22.149
2	14.178	22.172
3	36.694	39.669
4	39.658	15.615
5	43.977	24.655
6	45.786	30.367

From Table II, the highest deformation value occurs at frequency of 36.694 Hz i.e. 39.669 mm.

C. Harmonic Analysis of FCMA

The Harmonic Analysis of FCMA results are shown in TABLE III. It is observed that amplitude of vibration increases from 20-25 Hz, the peak value amplitude of vibration occurs at 26 Hz i.e. 3.513 mm. Then, again from 27-30 Hz frequency range the amplitude of vibrations are decreases.

Table III. Harmonic Analysis Of Fcma

Sr. No.	Frequency Value (Hz)	Amplitude (mm)
1	20	0.071
2	21	0.081
3	22	0.098
4	23	0.123
5	24	0.176
6	25	0.275
7	26	3.513
8	27	0.242
9	28	0.108
10	29	0.057
11	30	0.031

D. Experimental Results

As the vibration testing of FCMA have been performed on the Mechanical Exciter Machine.

Table IV. Vibration Testing Of Fcma

Sr. No.	Frequency Value (Hz)	Amplitude (mm)
1	20	0.066
2	21	0.074
3	22	0.103
4	23	0.128
5	24	0.190
6	25	0.288
7	26	3.720
8	27	0.260
9	28	0.105
10	29	0.060
11	30	0.033

So, Table IV shows, the amplitude values (mm) for respective frequency value. From this table, it is observed that amplitudes of vibrations increases from 20-25 Hz. Peak occurred at 26 Hz i.e. 3.720 mm. Again amplitude values decreases from 27-30 Hz.

IX. FEA CORRELATION

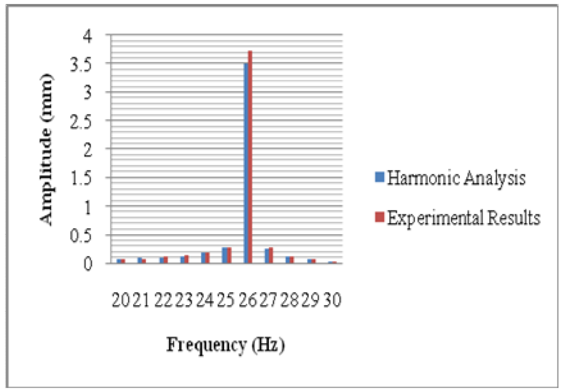

Fig. 10. FEA Correlation Bar Graph.

Fig. 10 shows, FEA Harmonic Analysis results and Experimental testing results have indicated on the bar type graph. From this graph, one can conclude that there is the good correlation between FEA Harmonic Results and Experimental Results. Even though some difference is seen between both results, it can be considered as minor deflection occurred during experimentation.

X. CONCLUSION

From the Finite Element Analysis, the natural frequency of the Fixture Table is more than the test specimen (FCMA) as well as working frequency range of the Mechanical Exciter Machine. Therefore, resonance will not occur in Fixture Table during vibration testing of FCMA.

The maximum frequency has been obtained by the Mechanical Exciter Machine is 50 Hz. So, this machine can be useful for vibration testing of small test specimens and at low frequency level.

On the comparison of Harmonic Analysis and Experimental Results, obtained results have been correlated. Some deviation in the results are occurred because of errors appeared in measurement of amplitude of vibration.

After experimentation, it is concluded that FCMA is undamaged up to 22 Hz frequency value but Load Cell gets fail in the frequency range of 24-28 Hz.

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