EFFECT OF TIP MASS ON TRANSVERSE VIBRATION MODES OF A GUN BARREL SUBJECTED TO RECOIL

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Abstract: This paper focuses on the calculation of modal frequencies and corresponding mode shapes for transverse vibration of Gun Barrel. The Barrel is considered as a cantilever beam. Recoil of Gun Barrel is incorporated as variation in the length cantilever beam and transverse vibration produces a band of frequencies in each mode. Further the effect of tip mass is considered and concluded that the band of frequency is shift to the lower side in each mode. The analysis and results discussed can be used for design and performance evaluation, selection of accessories and attachments of gun systems.

IndexTerms **- barrel vibration, gun barrel recoil, modal analysis, modal frequencies, natural frequency, Transverse Vibration Modes.**

I. INTRODUCTION

Recoil is due to the backward momentum of a gun when projectile is fired. The recoil caused by the gun balances the forward momentum of the projectile and exhaust gasses. In the higher caliber guns such as artillery and tank guns, the momentum is transferred to the ground through its mount. In order to bring the gun to a halt, a forward counter-recoil force is applied to the gun over a period of time. Generally, the counter-recoil force is smaller than the recoil force, and is applied over a time period that is longer than the time that the recoil force is being applied. The moving part of the gun due to recoil or counter-recoil is termed as ordnance and barrel is a component of the ordnance which facilitates the forward momentum to a projectile due to impulse transferred by high pressure propellant gases. The reaction of the forward momentum is observed as recoil. During recoil, gun barrel slides backward in a supported path. The gun barrel can be modelled as a cantilever beam. The downward deflection of the gun barrel due to gravity produces a curvature. Transverse vibration is induced to the gun barrel due to the curvilinear motion of the projectile. In case of beam vibration, the mode shapes and modal frequencies are related to its length. Similar is the case for a gun barrel which is approximated to cantilever beam. Further, the vibrating part of barrel length reduces due to the barrel recoil. Therefore, the transverse vibration of a recoiling gun barrel can be studied as variable length cantilever beam and the recoil of the gun barrel can be modelled as the axial movement of the beam. This paper focuses on the calculation of modal frequencies and corresponding mode shapes of a gun barrel subjected to recoil by analytical method as well as the Finite Elements Method.

Wickert and Mote [1] have provided a comprehensive review on the vibration and related aspects due to axially moving mass. Kong and Parker [2] employed a perturbation method to find closed-form, approximated Eigen solution for transverse vibration of axially moving beams with small bending stiffness. In particular, Ozkaya and Parkdemirli [3, 4] studied the transverse vibration of an axially moving beam in which axial velocity was harmonically varying about a mean velocity. Stylianou and Tabarrok [5] studied the axially moving beam through finite element method. P. Lisý, M. Štiavnický [6] presented modal analysis of barrels for assault rifles. The calculation of natural frequencies and corresponding mode shapes was performed using the Finite Elements Method. Various sizes of natural frequencies versus corresponding modes are shown. Xiao Shifu et al. [7] established modal test of a cantilever beam with tip mass.

The objective of the present paper is to find out the modal frequencies for an axially translating or sliding gun barrel, simulating its recoil. The basic configuration of the gun barrel which can recoil through cylindrical support is depicted in Fig.1.

II. THEORETICAL MODEL FOR GUN BARREL VIBRATION

Using Euler-Bernoulli Beam equations the transverse vibration can be modelled as:

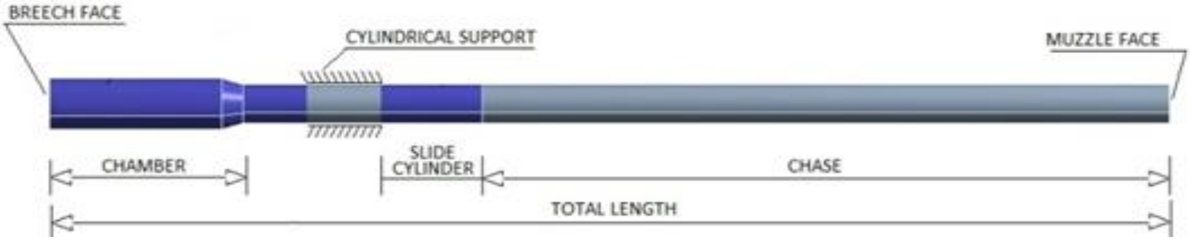

Fig. 1. Basic view of a Gun Barrel with Recoil

The following relation is obtained applying fixed-free beam

$$\boxed{\frac{\partial^2}{\partial x^2}\left(EI(x)\frac{\partial^2 u}{\partial x^2}\right)+m(x)\left(\frac{\partial^2 u}{\partial t^2}\right)=f(x,t)} \qquad (1)$$

Boundary condition,

$$\cosh \beta L \cos \beta L + 1 = 0 \qquad (2)$$

Equation (2) is solved numerically for β_n where the subscript, n, denotes the modes. Table (1) gives the first five $\beta_n L_n$ values which satisfies equation (2), where L_n is the free length of the beam.

TABLE 1 : Calculated Value Up To 3 Roots

n	1	2	3
$\beta_n L_n$	1.8751	4.6940	7.8547

So, the modal frequency for the gun barrel would be:

$$\boxed{f_n = \frac{(\beta_n L_n)^2}{2\pi}\sqrt{\frac{EI(x)}{m(x)\,L^4}}} \qquad (3)$$

III. NUMERICAL ANALYSIS USING FEA

a) GUN BARREL 3-D MODEL

Gun barrel 3-D model is created using CATIA V5 modelling software and after then the 3D model is imported to ANSYS 14.0 for further analysis. The chamber part is housed inside the cradle and the part hanging outside the cylindrical support is allowed to vibrate. The mesh model or finite element model is shown in Fig. 2 & Fig. 3 corresponds to the model with tip mass. The gun barrel is assumed to have isotropic material. The bore has 155mm diameter and other input are given in Table (2) & (3). The chamber part is housed inside cradle and part hanging outside the cylindrical support is allowed to vibrate.

TABLE 2 : Material properties

Young's Modulus (E)	2.e+011 [Pa]
Poisson's Ratio (μ)	0.3
Density (ρ)	7850 [kg/m3]

TABLE 3: Geometry of gun barrel

Total length of barrel	8.060 [m]
Chase length	4.373 [m]
Slide cylinder length	1.000 [m]
Inner diameter of barrel	0.155 [m]
Outer diameter of barrel	0.275 [m]

Fig. 2. Gun Barrel without tip mass
(a.) solid model (b.) meshed model

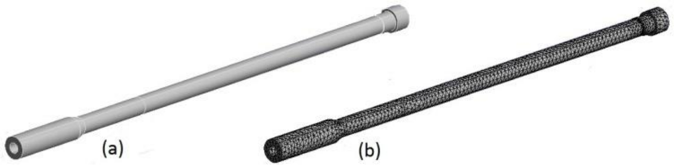

Fig. 3. Gun Barrel with tip mass of 100 kg
(a.) solid model (b.) meshed model

b) MODAL ANALYSIS

The modal analysis was performed to find out the modal frequency and mode shape in the transverse mode of the Gun Barrel while it is moving backward due to recoil. During recoil the barrel is sliding towards the fixed support and as the barrel slides, the length is reduced from free to fixed end. Modal analysis was done for 0 m to 1 m slide (in 20 steps) and first three modes for initial start without slide for different Tip mass are shown in Fig.4 and Fig. 5.

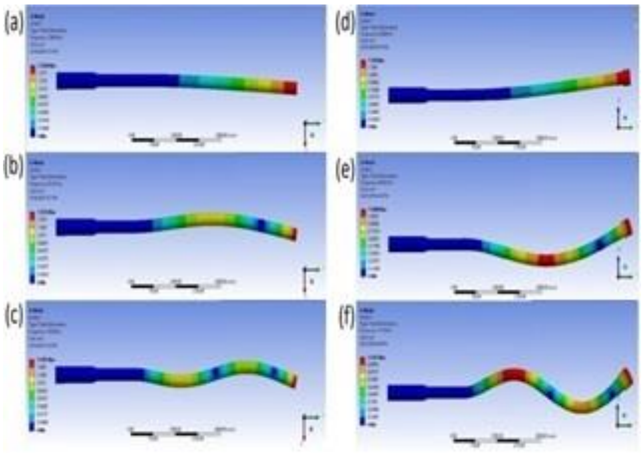

Fig. 4. Without Tip mass
(a)1st mode shape (b) 2nd mode shape (c) 3rd mode shape
With 100 kg Tip mass
(d) 1st mode shape (e) 2nd mode shape (f) 3rd mode shape

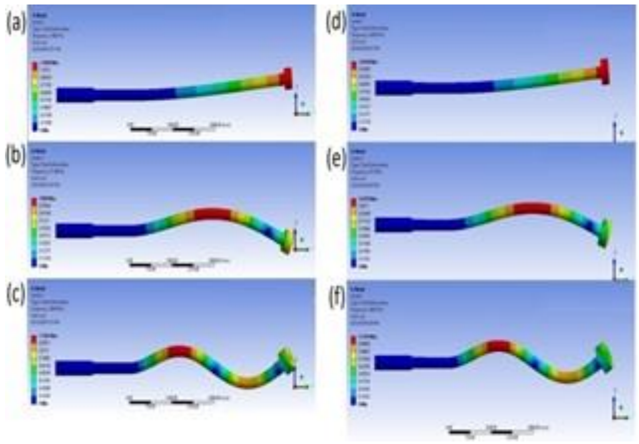

Fig. 5. With 300 kg Tip mass
(a)1st mode shape (b) 2nd mode shape (c) 3rd mode shape
With 500 kg Tip mass
(d)1st mode shape (e) 2nd mode shape (f) 3rd mode shape

IV. RESULTS OF MODAL ANALYSIS

The results for the first three modal frequencies evaluated analytically by using the equation (3) and numerically by FEA are tabulated in Tables (4), (5) and (6). Both the data are matching with in limited errors. The matching is more accurate in lower frequencies. The increasing trends in the modal frequencies due to barrel recoil are depicted in Fig. 6, Fig. 7 and Fig. 8.

TABLE 4: 1st mode frequency of Gun barrel corresponding to recoil length

	Without Tip mass			Tip mass 100 kg	Tip mass 300 kg	Tip mass 500 kg
Recoil length (m)	Theo. (f_n) (Hz)	FEA (f_o) (Hz)	% Error	FEA (f_o) (Hz)	FEA (f_o) (Hz)	FEA (f_o) (Hz)
0	7.72	7.66	0.72	6.28	5.40	4.83
0.2	8.33	8.27	0.66	6.73	5.76	5.14
0.4	9.01	8.94	0.66	7.23	6.17	5.49
0.6	9.78	9.71	0.70	7.78	6.61	5.88
0.8	10.7	10.57	1.18	8.40	7.11	6.31
1	11.7	11.55	1.23	9.11	7.67	6.79

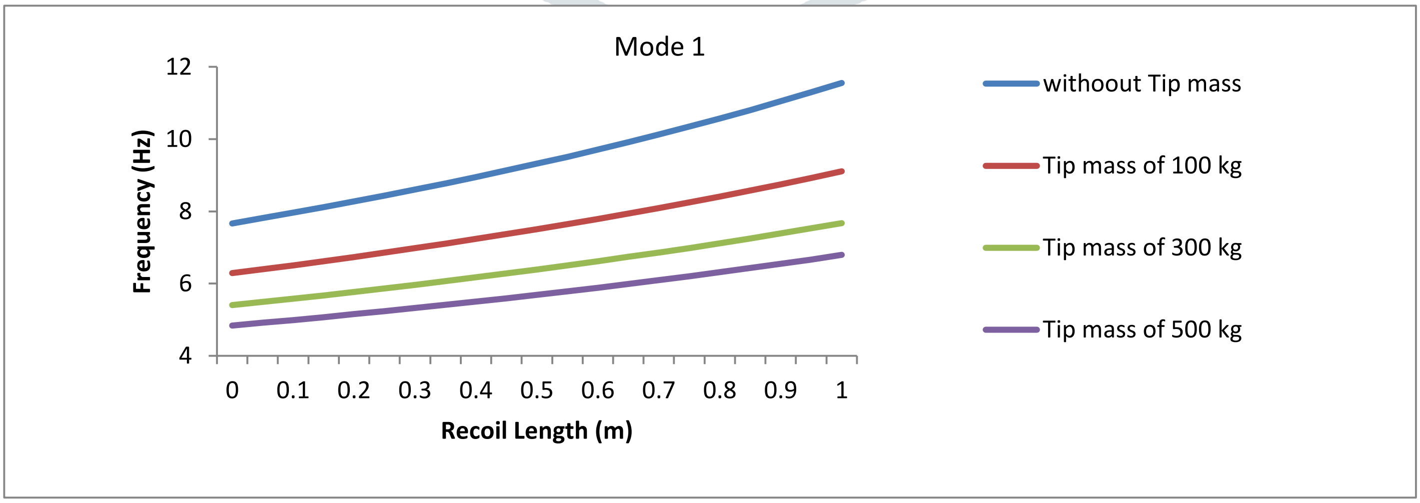

Fig. 6. Mode 1 Frequency with Recoil Length of the Gun Barrel

TABLE 5: 2nd mode frequency of the Gun Barrel corresponding to recoil length

	Without Tip mass			Tip mass 100 kg	Tip mass 300 kg	Tip mass 500 kg
Recoil length (m)	Theo. (f_n) (Hz)	FEA (f_o) (Hz)	% Error	FEA (f_o) (Hz)	FEA (f_o) (Hz)	FEA (f_o) (Hz)
0	48.4	47.33	2.19	40.24	37.28	35.79
0.2	52.2	51.05	2.19	43.14	39.96	38.35
0.4	56.5	55.14	2.39	46.38	42.93	41.19
0.6	61.3	59.75	2.52	49.99	46.24	44.37
0.8	66.8	64.95	2.76	54.05	49.97	47.93
1	73	70.86	2.92	58.63	54.17	51.95

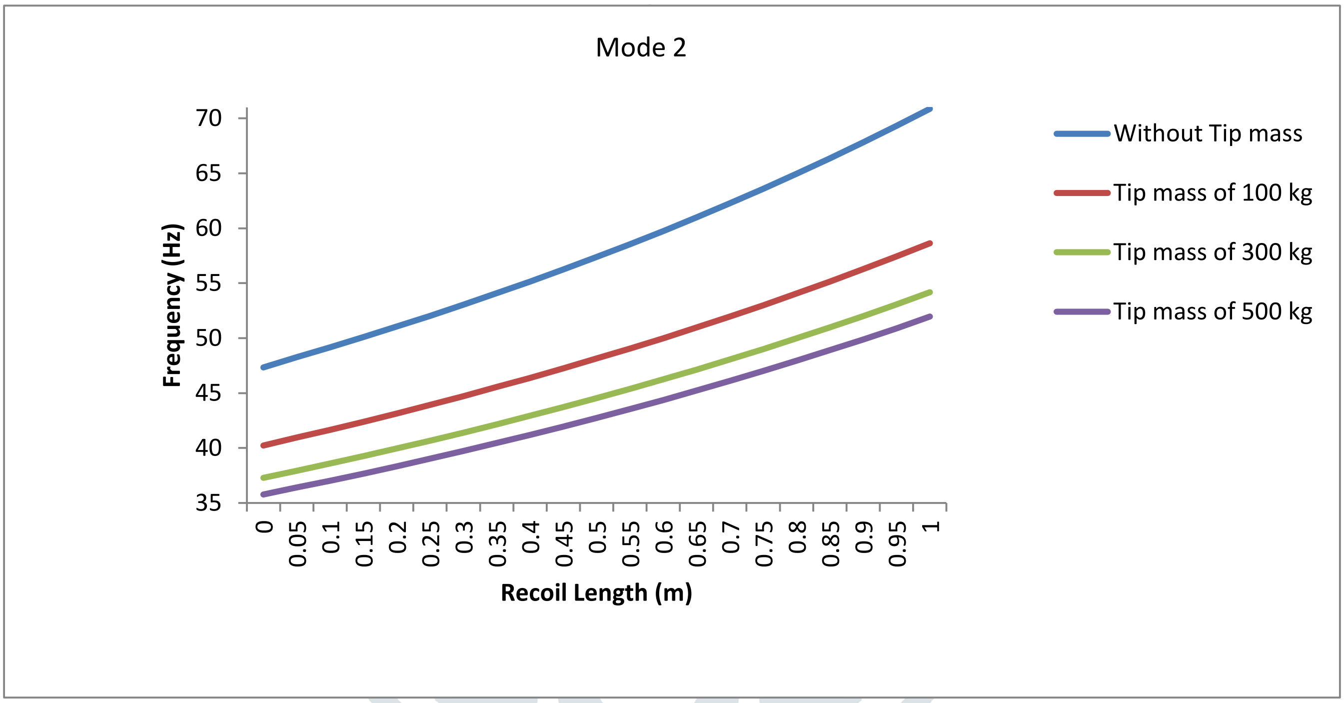

Fig. 7. Variation of Mode 2 Frequency with Recoil Length of the gun barrel

TABLE 6: 3rd mode frequency of the Gun Barrel corresponding to recoil length

	Without Tip mass			Tip mass 100 kg	Tip mass 300 kg	Tip mass 500 kg
Recoil length (m)	Theo (f_n) (Hz)	FEA (f_o) (Hz)	% Error	FEA (f_o) (Hz)	FEA (f_o) (Hz)	FEA (f_o) (Hz)
0	135	129.58	4.01	112.56	106.98	104.01
0.2	146	139.52	4.43	120.59	114.61	111.33
0.4	158	150.44	4.78	129.56	123.05	119.44
0.6	172	162.67	5.42	139.49	132.44	128.44
0.8	187	176.43	5.65	150.69	142.95	138.46
1	205	191.98	6.35	163.24	154.76	149.7

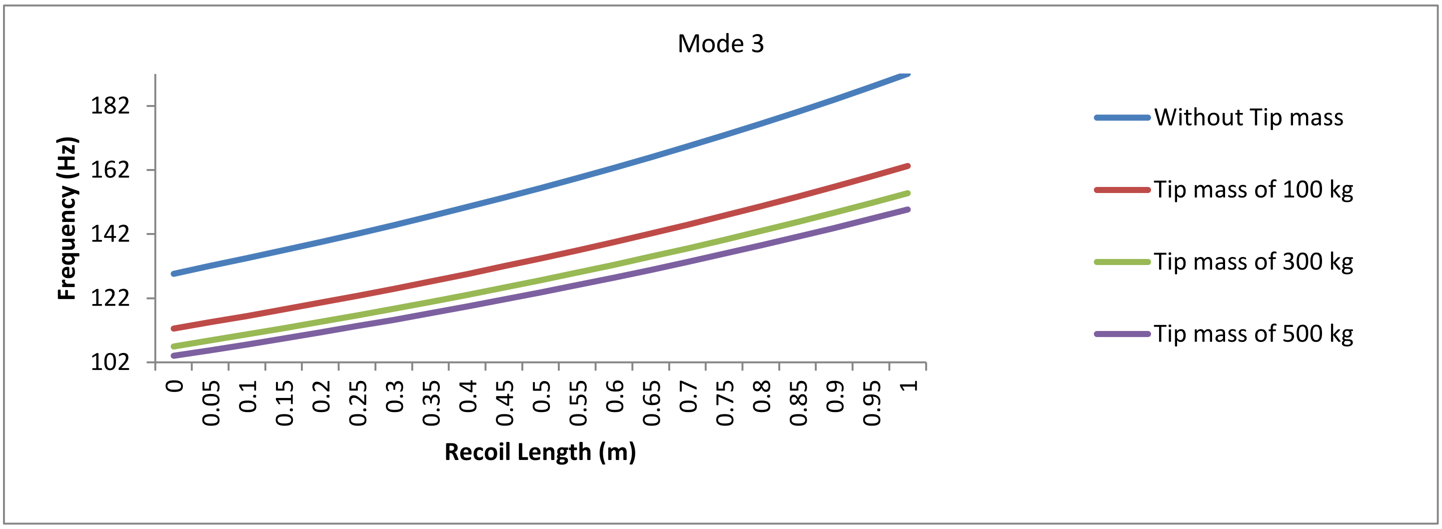

Fig. 8. Variation of Mode 3 Frequency with Recoil Length of the Gun Barrel

V. ANALYSIS & OBSERVATION

There is a close agreement between the theoretical prediction and numerical evaluation using FEA for the modal response of the gun barrel. Axially moving variable length cantilever beam model is therefore suitable for modal analysis of a gun barrel having recoil. It is observed that as the barrel recoils there is an increase in the frequency for all three modes and as the tip mass are added to the free end of gun barrel there is a trend of shift the frequency to Lower side for all three modes. When the barrel is recoiling the frequencies are observed in a band as compared to single value in fixed length non-recoiling gun barrel vibration counterpart.

The percentage of variation of modal frequency with added Tip mass for first mode has 38.50 % of variations, second mode has 25.52 % of variations and 20.85 % of variations is observed in third mode. This is an important observation for the system designers who are involved in fixing equipment and accessories on to the gun systems so that resonating frequencies are avoided from the gun system frequencies. This can isolate the failure and damage of such accessories attachments due to resonance.

VI. CONCLUSION

The modal analysis using both analytical and FEA has been carried out for the transverse vibration of a recoiling gun barrel. It has been found out that when the barrel recoils, the frequencies of all transverse vibration modes are increasing and when the tip mass is added to the barrel free end the frequencies of all transverse vibration modes are shift to Lower side. The increasing trend for Recoil is due to the reduction in the length of vibrating part of the gun barrel and the decreasing trend for added Tip mass is due to increase in the transverse inertia of the gun barrel. The analytical and FEA results are in close agreement. The recoil of barrel produces a band of frequencies in all modes. This band of frequency is shift in the frequency of the order of 30% towards lower side is observed due to addition of tip mass in the range of 100 kg to 500 kg. The shift of band of frequency for recoil characteristic gun barrel can be used to predict the possible frequency band in different modes and accordingly all accessories and equipment to be mounted on the system can be selected to avoid any damage due to resonance improving both design and system performance.

NOMENCLATURE

ρ	Material density
E	Young's Modulus
f_n	Modal frequency by analytic method
f_o	Modal frequency by FEA
I	Moment of inertia
L_n	Barrel free length
m	Mass per unit length
M	Tip mass

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