

# Analysis and Design Optimization of Rotary Balance Test Rig

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**ABSTRACT:** The rotating parts of a machine are very important from the perspective of high speed machinery since they create centrifugal force of higher magnitude. It will result in unbalance and leads to high vibration levels. This paper is focussed on balancing of eccentric mass which is attached to a Circular arc member of a Rotary balance test rig which is used to test Spinning manoeuvre of fighter aircraft models and comparing static stress to dynamic stress to optimize the design test rig by changing into new material.

**KEYWORDS:** Angle of attack (AOA), Centrifugal force, Eccentric mass, Dynamic Analysis.

## I. INTRODUCTION

Rotary balance test is carried out to determine the various aerodynamic forces and moments which are acting on fighter aircraft during coning motion or spinning motion of aircraft. The scaled model of fighter aircraft is used for the test. The test rig imparts coning or rotary motion to the model of aircraft. The aerodynamic parameters are determined at different speeds and various angle of attack with the help of six component strain gauge balance. The forces along 3 axes and corresponding moments along 3 axes are measured using strain gauges according to K.J.Orlik et al [3].

The main components of the test rig include Sting, Cranked bracket, Sliding block, Circular arc member. The Sting will hold the aircraft model at a particular AOA. Sting is attached to cranked bracket and it will help in holding sting at required position. The Cranked bracket is connected to sliding block which will help in moving the eccentric assembly of previous components over Circular Arc member. The Circular arc member is attached to shaft with the help of interface member. Shaft is supported in roller bearing and connected to DC motor with the help of gears. The test rig is made to rotate at speeds ranging 300 rpm to 600 rpm. Signals are obtained from Strain gauge balance placed inside aircraft model. The wind is blown at 45m/s. Entire test rig is placed in open channel wind tunnel according to M.A.Ramaswamy et al [2].

Figure 1 shows the photograph of Rotary test rig. It contains eccentric masses attached to circular arc member. The eccentric load is induced on the Circular arc member because of Sting, Cranked bracket and Sliding block due to distance between individual centre of gravities from the axis of rotation. This will create centrifugal force which will act through combined centre of gravity of the eccentric mass. The attempt is done to balance the eccentric mass and comparison is drawn between stresses caused by static and dynamic forces to change the material of test rig for optimization of existing design.

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Figure 1: Photograph of rotary test rig

## II. STATIC ANALYSIS

Table 1 shows the input forces and moments considered for static analysis. The forces acting on the test rig when it is stationary are taken into account. This includes the forces due blowing wind which will act on aircraft model and weight of individual components. The blowing wind will induce forces and moments at the focal point of test rig. These forces are taken as input forces and they are transferred to connected components by load path mechanism. Thus the forces acting on each component are evaluated.

Table 1: Inputs Considered for static analysis

Inputs	Magnitude
Normal force	600 kg
Side force	150 kg
Drag force	120 kg
Twisting moment	120 kg-m
Rolling moment	120 kg-m
Yawing moment	120 kg-m
Model weight	20 kg

Table 2 shows reaction forces and moments at fixed end of each components. The reaction forces and moments at end of each component are transferred to next component as input and thus the resultant forces acting on each component are determined.

Table 2: Reaction forces and moments along X, Y, Z direction

	$F_x$ (N)	$F_y$ (N)	$F_z$ (N)	$M_x$ (N-mm)	$M_y$ (N-mm)	$M_z$ (N-mm)
<b>Sting</b>	6236.7	-1471.5	-1177.2	$0.1172 \cdot 10^7$	$2.11778 \cdot 10^7$	$2.4280 \cdot 10^7$
<b>Cranked bracket</b>	-3967.4	-1471.5	-5542.8	$0.1591 \cdot 10^7$	$0.963 \cdot 10^7$	-87907
<b>Tapered beam</b>	166.75	-1471.5	-6754.4	$0.5865 \cdot 10^6$	$-0.97095 \cdot 10^7$	$0.11674 \cdot 10^7$
<b>Straight beam</b>	-2264.3	-1471.5	-6523.3	$0.5998 \cdot 10^6$	$-0.93133 \cdot 10^7$	$0.9526 \cdot 10^6$

These results are verified by using ANSYS software and design of each component is carried out. Stresses are estimated for each components by theoretical approach. Von-mises stress are calculated each part. The vector mechanics approach was also used to verify the above results.

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Figure 2 shows Von-mises stress distribution for tapered beam of circular arch. The circular arc section is divided into tapered beam and constant cross section beam. It shows maximum Von-mises stress of 31.2574 N/mm<sup>2</sup>. It is observed near loading end.

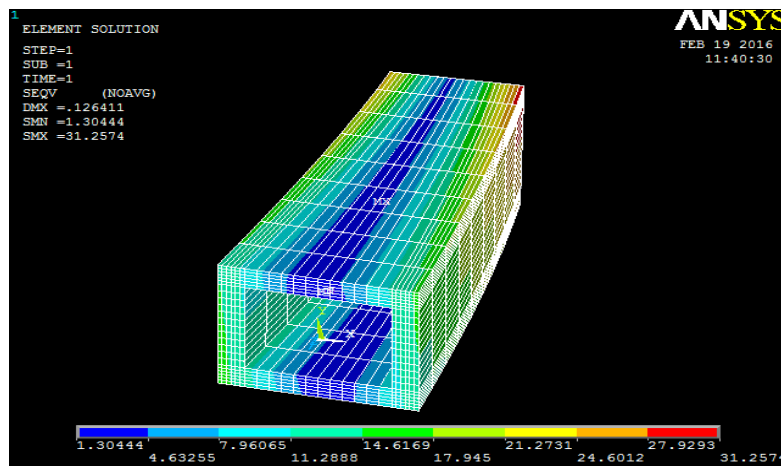


Figure 2: Von-mises stress distribution for tapered beam of circular arch

Figure 3 shows Von-mises stress distribution for constant cross section beam of circular arch. It indicates maximum Von-mises stress of 16.4835 N/mm<sup>2</sup>. It is also observed near loading end.

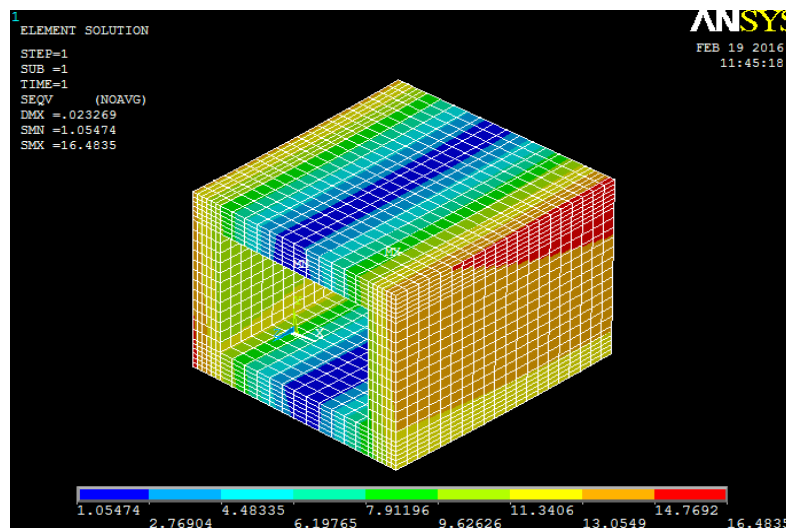


Figure 3: Von-mises stress distribution for constant cross section beam of circular arch

### III. DYNAMIC ANALYSIS

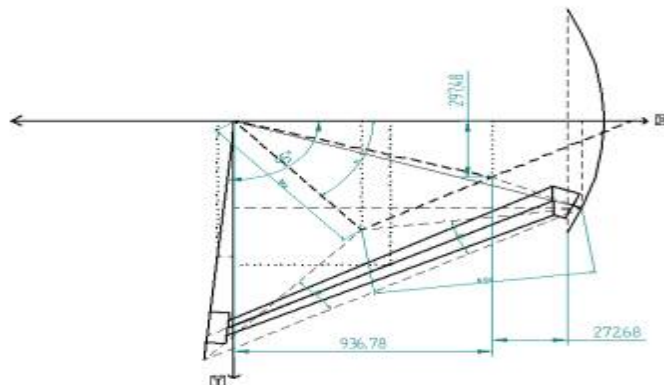
Figure 4 shows position vector graph for calculating combined centre of gravity. It is plotted by considering individual position vectors of centre of gravity of each components. The mass attached to Circular arc section will cause the centre of gravity to shift to a certain distance from axis of rotation. Thus when the test rig is subjected to rotation, the centrifugal force will be developed and it will cause unbalance. This has to be taken care by calculating the magnitude

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and location of balancing mass. In the existing test rig, the balancing mass was placed on top of circular sector. It resulted in development of dynamic couple which lead to higher vibrations. Hence it is decided to place the balancing mass in the same line of action of centrifugal force.



**Figure 4: Position vector graph for determining combined centre of gravity**

The centrifugal force was calculated and it was found to be 58.042 kN. This value is used for calculating balancing mass. It was decided to keep balancing mass at a distance of 0.505 m due to restriction from design consideration. The balancing mass is calculated by equation shown below,

$$m_2 = ((m_1 \times r_1) \div r_2) \quad (1)$$

The distance  $r_2$  set at 0.54043 m from axis of rotation and balancing mass to be placed is found to be 108.193 kg.

## IV. CONCLUSION

The centrifugal force (58.042 kN) obtained is found to approximately ten times higher than maximum static force (6236.7 N) in the same direction. It will result in dynamic stress to be ten times higher than static stress. This will be greater than yield stress of mild steel (244.4 N/mm<sup>2</sup>). Hence the existing material (mild steel) of test rig should be changed to other material which is having higher yield strength. It is also found that by placing balancing mass in the same plane as that of centrifugal force will nullify the unbalancing couple which is causing large vibration. Thus the design of existing test rig is optimized by changing of material from mild steel to a different material having higher yield strength and also by changing the plane of balancing mass to action plane of centrifugal force.

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