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Experimental Analysis of Brake Induced Vibration in the Aircraft Rolling: Technical Note

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ABSTRACT:

This paper deals with the study of vibration analysis of the rolling aircraft tyre in various frequency conditions on free and braking conditions. This paper develops mathematical model for tyre and generates dynamic equations for numerical simulations in Matlab Simulink. The experimental test facility has been developed to measure the vibration parameters while rolling the tyre with load or no load conditions. Finally, the analysis has been carried out and the levels of vibration were measured experimentally.

KEYWORDS:

Mathematical modelling; Rotating tyre; Vibration; Frequency; Braking; Speed; Dynamic model; Matlab Simulink

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1. Introduction

Aircraft tyres are critical components that must meet high quality standards. Low frequency tyre vibrations can affect the aircraft landing while moving on the airport tarmac and may cause undesired fatigue-inducing vibration in the landing gear. Vibration analysis [1] can characterize the tyre dynamics, determine the fundamental frequencies and define a complete model of the tyre. From this model, Engineers can objectively evaluate their concerns about the impact of vibration on adjacent aircraft components. These concerns have very real consequences since excessive vibration can lead to premature component fatigue and failure. Tyres interface the road and vehicle, so they are the links through which forces are exchanged. The presence of these forces can cause losses of energy, vibration and noise [3]. Under this point of view, the study of tyre vibration behaviour becomes a fundamental importance. Vibration, shimmy and other similar conditions are usually blamed on improper tyre balance [2-3]. Imbalance is a well-known and easily understood cause for vibration. There are a number of specific aspects of the tyre, wheel and gear assembly which can be the cause or contribute to aircraft vibration as with any concern, a systematic approach should be taken to isolate its cause.

Brake induced vibrations is one the problem faced today by the aircraft community. Excessive landing gear vibration may shorten the gear life, affect the comfort to the pilot and passenger and potentially lead to fatal accidents due to excessive wear. Among the most important reason for the landing gear vibration are unsuitable combination of structural stiffness, damping and pneumatic tyre characteristic [2]. Furthermore an unlikely combination of brake system design with the tyre physics can produce a serious vibration problem. Brakes may chatter or squeal when the linings do not ride smoothly and evenly along the disc. A warped disc(s) in a multiple brake disk stack produces a condition wherein the brake is actually applied and removed many times per minute. This causes chattering and at high frequency it causes squealing. Discs that have been over heated may have damaged the surface layer of the disc. Some of this mix may be transferred to the adjacent disc resulting in uneven disc surfaces that also leads to chatter or squeal.

In addition to the noise produced by the brake chattering and squealing vibration is caused that may lead to further damage of the brake and the landing gear system. The technician must investigate all reports of brake chattering and squealing. A flat spot on a tyre is the result of the tyre skidding on the runway surface while not rotating. This typically occurs when the brake lock is on while the aircraft is moving. If the flat spot damage does not expose the reinforcing ply of a bias tyre or the protector ply of a radial tyre, it may remain in service. However if the flat spot causes vibration, the tyre must be replaced. Landing with a brake applied can often causes a severe flat spot that exposes the tyre under tread. It can also cause a blowout.

The study of vibration analysis of the rolling aircraft tyre in various frequency conditions has been carried out experimentally. For this experiment, a new test rig was set up and data acquisition system was established. The mathematical equations and dynamic model are developed for numerical simulations in Matlab Simulink. Based on the dynamic model inputs to the test rig, the accelerations of vibration are obtained and analysed. The obtained test results indicate that the designed vibration rig can be effectively used for various frequency levels and load levels to the tyres for typical aircraft rolling.

2. Mathematical model and simulation

Mathematical modelling of rolling tyre at various frequencies has been investigated theoretically first and also experimentally. The two degrees of freedom tyre model has been developed for vibration analysis of tyre rolling at different speeds and braking conditions. In this model the tyre tread and tyre belt are lumped as mass M and m. Different stiffnesses are introduced in this model. Vertical stiffness k_v is used to model tyre bending. Enveloping stiffness is introduced to consider deformation due to protuberances or cleats on the road. k_{e1} is the stiffness between tread and road. k_{e2} is the stiffness between the tread and belt. The sidewall stiffness k_s is introduced between the wheel and belt. The schematic of the tyre ride model is shown in Fig. 1.

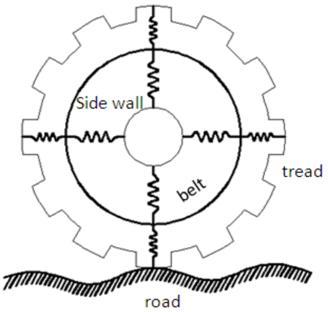

Fig. 1: Schematic diagram of tyre ride model

The mathematical model of rolling tyre is shown in Fig. 2. From this model, the equations of motion [5] are derived as follows,

$$m\ddot{y}_1 + (k_s + k_{e2})y_1 - k_{e2}y_2 = k_v(y - y_1) \quad (1)$$

$$M\ddot{y}_2 + (k_{e2} + k_{e1})y_2 - k_{e1}y_1 = k_{e1}y \quad (2)$$

$$\begin{pmatrix} m & 0 \\ 0 & M \end{pmatrix}\begin{pmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{pmatrix} + \begin{pmatrix} k_{e2}+k_s & -k_{e2} \\ -k_{e2} & k_{e2}+k_{e1} \end{pmatrix}\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} k_v \\ k_{e1} \end{pmatrix}\begin{pmatrix} y-y_1 \\ y \end{pmatrix} \quad (3)$$

The general equation in the matrix formulation is written as follows,

$$M\ddot{Y} + KY = F(t) \quad (4)$$

Where M - Mass matrix, K - Stiffness matrix, F - Force vector and Y - Displacement vector. The developed equations of motion have been used for generating the dynamic model in Matlab Simulink. The numerical simulations give vibration parameters at different frequencies of rolling tyre. The assumed sine wave input of frequency of 15 Hz and 21 Hz. The peak value of acceleration is measured and can be compared with experimental results.

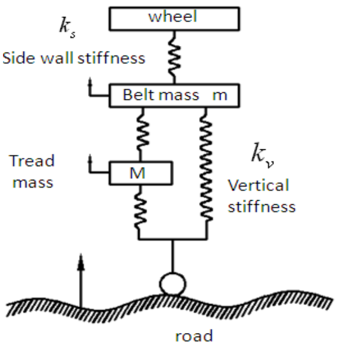

Fig. 2: Mathematical model of rolling tyre

3. Experimental setup

The tyre is installed in the test rig with the data acquisition system as shown in Fig. 3. By using twister aluminium plate, the fixed accelerometer is made to rest on the moving tyre to record the vibration in both X and Y axes while the tyre is rotated at different frequencies with the electric motor controlled by alternator. External wires are used to connect the accelerometer with data acquisition system (µC). The data acquisition system is connected to laptop through FT 232 chip (USB to USART convertor). A flow chart for the experimental analysis [4] is shown in Fig. 4.

Fig. 3: Experimental test set up for measuring vibrations of rotating tyre

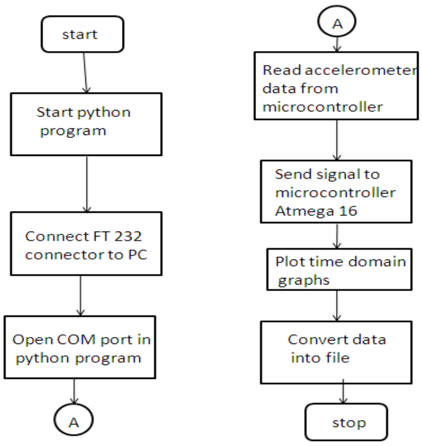

Fig. 4: Flow chart for experiment analysis

4. Results and discussion

The tyre is rotated initially without load applied at frequency of 15 Hz and 21 Hz. The recorded vibrations on both X axis and Y axis are shown in Figs. 5 and 6. The coupling is released and the brake load is applied as 5kg at 15 Hz and 9kg at 21 Hz frequency of rotation. The data acquisition system follows the flow chart as shown in Fig. 4 to measure the vibrations during rotation of tyre and in the braking conditions. The accelerations of vibration in X-axis and Y-axis for loaded tyre with 5kg at 15 Hz and 9kg at 21 Hz are shown in Fig. 7 and Fig. 8 respectively. The experimental results shown are useful for analysing the brake induced vibration of aircraft rolling tyre under no load and brake load conditions. The peak amplitude of vibration acceleration under 9kg load at 21 Hz is higher than the no load condition as well as 5kg at 15 Hz conditions as expected. The Y-axis vibration acceleration amplitudes are higher than the X-axis vibration acceleration amplitudes over the time period of the experimental analysis.

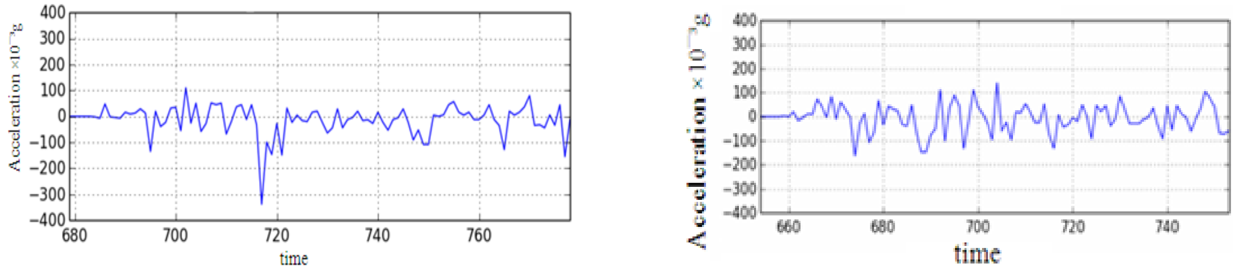

Fig. 5: X-axis (left) and Y-axis (right) acceleration for tyre rotation at 15Hz with no load condition

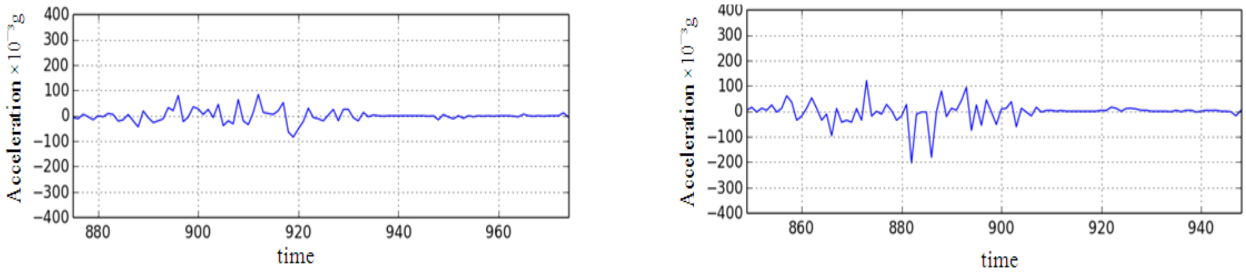

Fig. 6: X-axis (left) and Y-axis (right) acceleration for tyre rotation at 15Hz with 5kg load

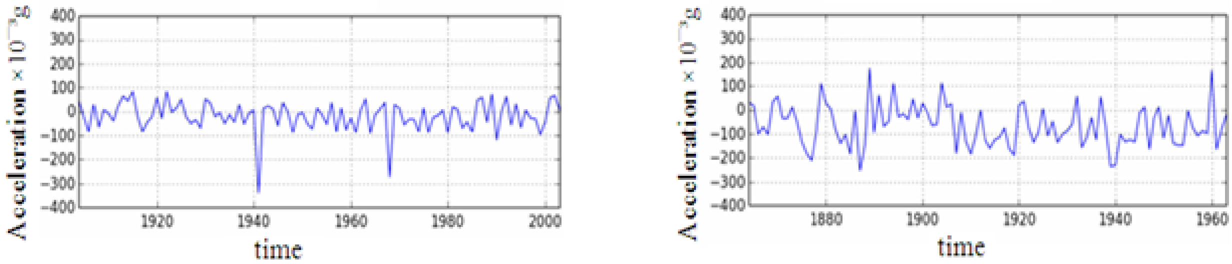

Fig. 7: X-axis (left) and Y-axis (right) acceleration for tyre rotation at 21Hz with no load condition

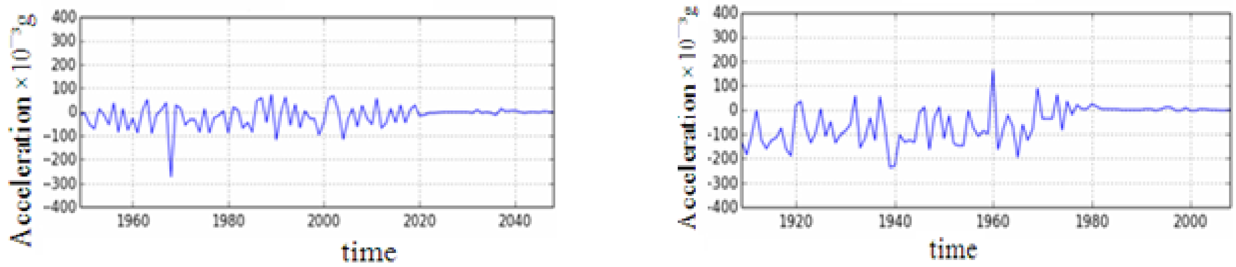

Fig. 8: X-axis (left) and Y-axis (right) acceleration for tyre rotation at 21Hz with 9kg load

5. Conclusions

A new test rig and data acquisition system was developed to experimentally study the tyre vibration under aircraft rolling conditions. The experiments were supplemented with a mathematical dynamic model using Matlab Simulink and Python for effective data acquisition of acceleration data and varying frequency and load level during test. As expected, the vibration acceleration amplitudes for loaded tyre rotating at higher frequencies are higher than that of under no load tyres or tyre rotating at low frequency.

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