Experimental nonlinear dynamic analysis of a machine supporting structure

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Abstract. We present an experimental study of the effects of geometric nonlinearities on vibrations of rotating machines support structures. Dynamic characteristics of structures depend on their stiffness, damping and mass. The initial stiffness of a structure, computed in its unloaded state, is affected by the applied forces, the so-called geometric stiffness. Compressive forces reduce the stiffness and the frequencies and may lead to buckling, for zero frequencies. In bases of machines excited by the supported equipment, vibrations may affect the structures but, in general, they may generate damage to the suspended equipment and the quality of the production. Although machine support structures are, as a rule, very bulky, little affected by geometric stiffness considerations, the tendency of modern structural engineering, especially in aerospace applications, is towards slender members, due to more efficient materials and powerful analysis tools. Here we study these effects via experimental methods designed to evaluate previous mathematical models. Our model is a metal beam under compression supporting a DC motor. We suppose the original design provided natural frequencies away from the excitation frequency. Nevertheless, the presence of large axial compressive force will reduce the beam stiffness and natural frequencies leading to unexpected, potentially dangerous resonance states. Experimental imperfections led to observation of interesting phenomena not predicted in our previous theoretical and numerical studies. We also observe, as expected, occurrence of the so called Sommerfeld Effect, when underpowered excitation sources get their rotation regime stuck at resonances.

Keywords: experimental dynamic analysis, nonideal motors, nonlinear dynamics of structures.

1 Introduction

We present an experimental study of the effects of geometric nonlinearities on vibrations of rotating machines support structures. Dynamic characteristics of structures depend on their stiffness, damping and mass. The initial stiffness of a structure, computed in its unloaded state, is affected by the applied forces, the so-called geometric stiffness. Compressive forces reduce the stiffness and the frequencies and may lead to buckling, for zero frequencies. In bases of machines excited by the supported equipment, vibrations may affect the structures but, in general, they may generate damage to the suspended equipment and the quality of the production. Although machine support structures are, as a rule, very bulky, little affected by geometric stiffness considerations, the tendency of modern structural engineering, especially in aerospace applications, is towards slender members, due to more efficient materials and powerful analysis tools. Here we study these effects via experimental methods designed to evaluate previous mathematical models. Our model is a metal beam under compression supporting a DC motor. We suppose the original design provided natural frequencies away from the excitation frequency. Nevertheless, the presence of large axial compressive force will reduce the beam stiffness and natural frequencies leading to unexpected, potentially dangerous resonance states. Experimental imperfections led to observation of interesting phenomena not predicted in our previous theoretical and numerical studies. We also observe, as expected, occurrence of the so called Sommerfeld Effect, when underpowered excitation sources get their rotation regime stuck at resonances. Earlier mathematical and numerical work is to be found in [1-3].

2 Experimental setup

2.1 The model beam

Figure 1 displays the experimental setup: a rectangular section steel bar mounted in a calibrated manual hydraulic press intended to apply large axial compressive forces in order to change its geometric stiffness. A small DC electric motor is fixed with PVC fixtures to the beam central section. Unbalanced forces are generated by wooden flywheels with attached small point masses. Several end conditions were studied: embedded ball point, simply cut etc.

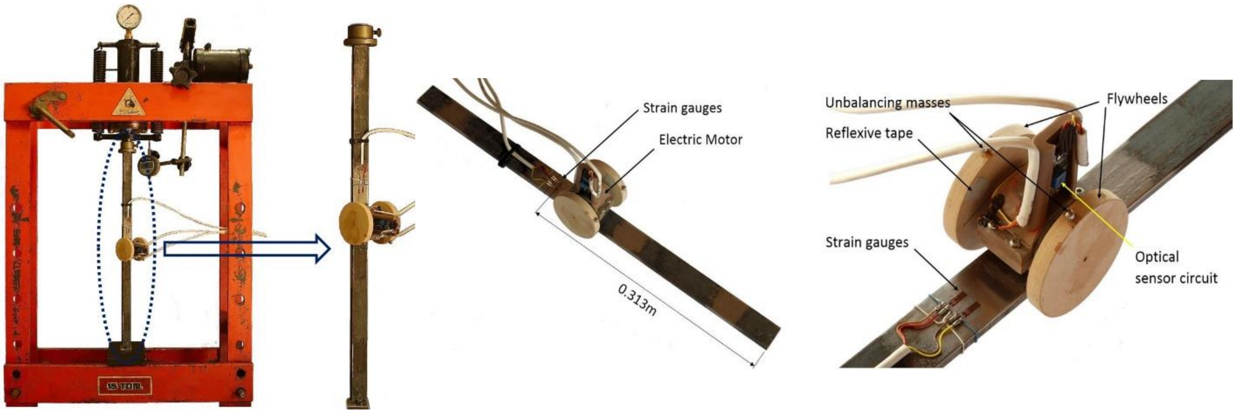

Figure 1. The experimental setup

2.2 Instrumentation

Data acquisition was carried out by an 8 channels automatic system coupled to a PC computer, with FFT capabilities. The sensor system comprises: piezoelectric accelerometers to pick up vibrations; strain gauges for strain and bending moments measurement; optical tachometer to access the motor rotation speed; an ad hoc designed power control and measurement digital electronic circuit, coupled to a DC supply.

3 Results and discussion

The effect of large compressive axial forces applied to the beam on the geometric stiffness and 1st free undamped vibration frequency was detected, as displayed in Fig. 2. Frequencies get smaller as the compressive axial force grows, up to a point, where large nonlinearities reverse the trend.

Effect of end conditions were also studied and presented in Fig. 2.

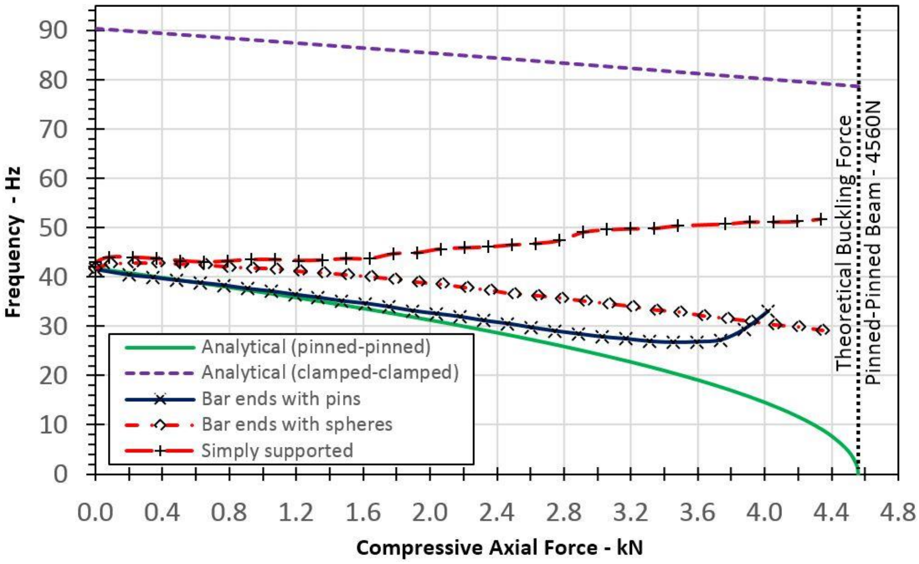

Figure 2: First vibration frequency as function of axial compressive force and end conditions

By controlling the amount of power available to the DC motor, the Sommerfeld effect was also observed, of getting stuck in resonance and occurrence of the jump phenomenon. Figure 3 displays measured forced vibrations accelerations as power is varied linearly from zero through resonance, for a certain value of axial compressive force. Motor angular velocity, measured by the tachometer, is also shown.

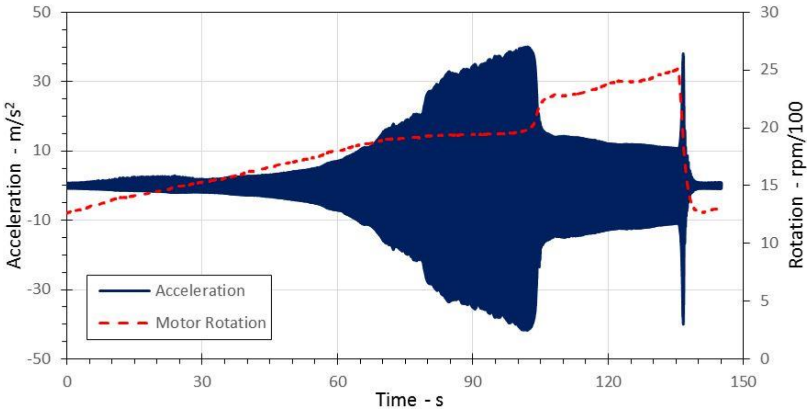

Figure 3: Accelerations and motor rotation speed as power is increased through resonance

Figure 4 is similar but displays bending strains in the beam.
Figure 5 shows power consumption and motor rotation during run-up.
Figure 6 plots supply voltage and motor rotation during run-up.

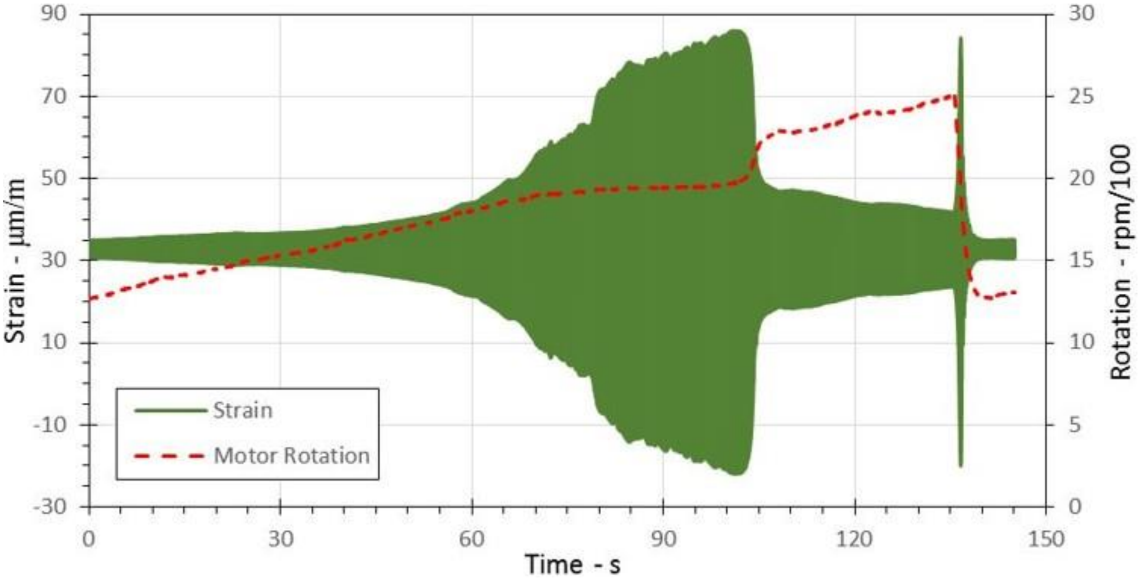

Figure 4: Bending strain and motor rotation speed as power is increased through resonance

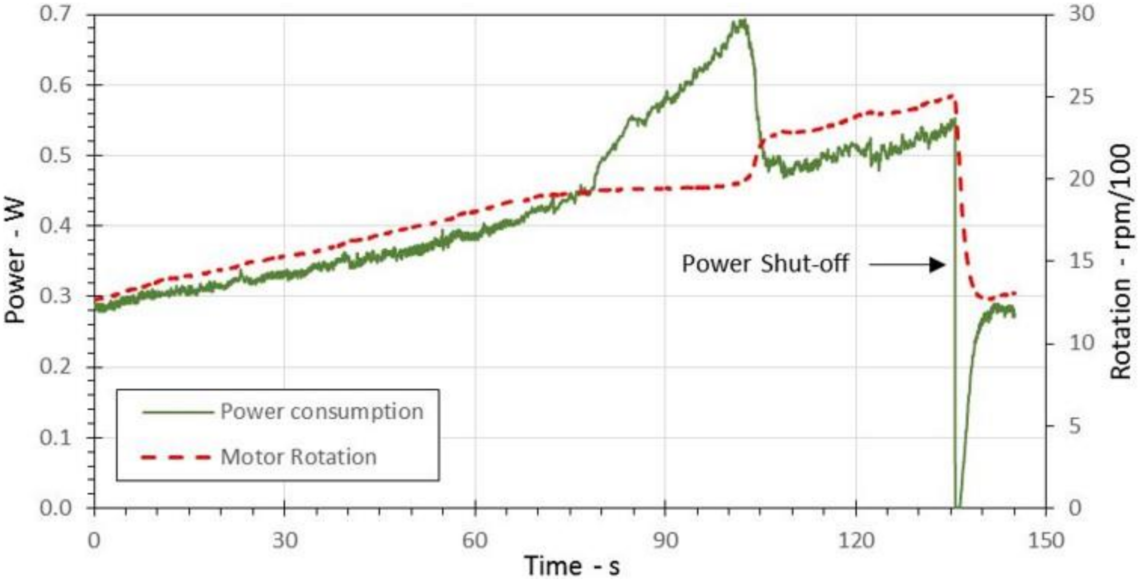

Figure 5: Power Consumption and Motor Rotation During Run-Up

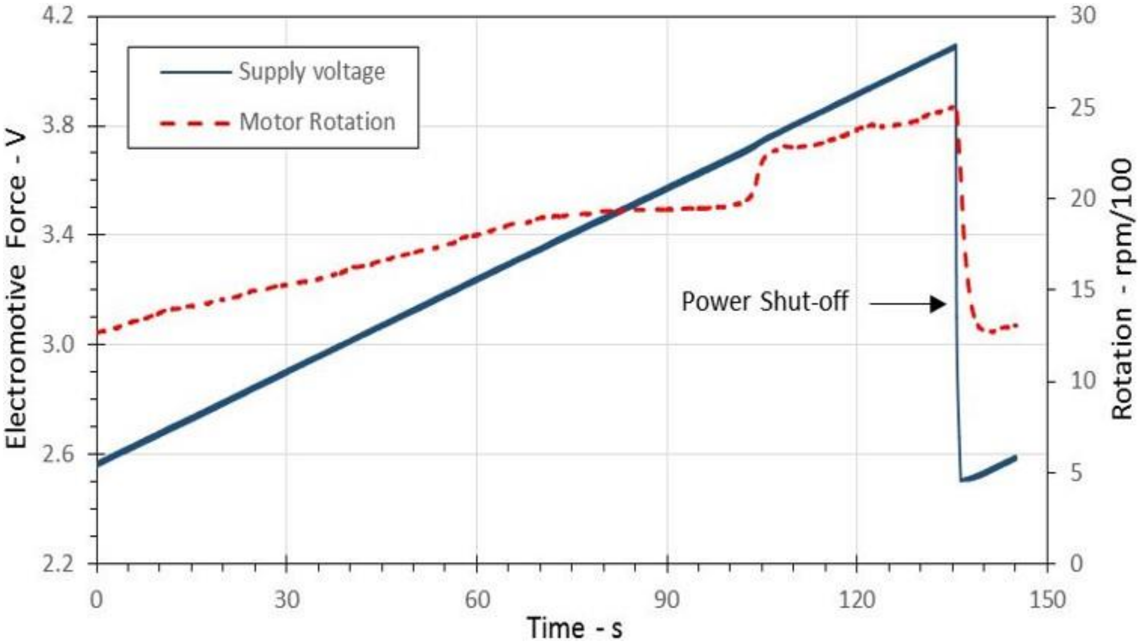

Figure 6: Supply Voltage and Motor Rotation During Run-Up

4 Conclusions

Experimental research was carried out on the nonlinear dynamics of a beam supporting a unbalanced rotating machine. The effect of large compressive axial forces upon the geometric stiffness and free undamped vibration frequencies was detected. Further, for underpowered machines, the Sommerfeld effect was also observed, of getting stuck in resonance and occurrence of jump phenomena. Effect of several end conditions was also studied.

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