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Machinery Resonance and Drilling

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ABSTRACT

New developments in vibration analysis better explain machinery resonance, through an example of drill bit chattering during machining of rusted steel. The vibration of an operating drill motor was measured, the natural frequency of an attached spring was measured, and the two frequencies were compared to show that the system was resonant. For resonance to occur, one of the natural frequencies of a structural component must be excited by a cyclic force of the same frequency. In this case, the frequency of drill bit chattering due to motor rotation equaled the spring frequency (cycles per second), and the system was unstable. A soft rust coating on the steel to be drilled permitted chattering to start at the drill bit tip, and the bit oscillated on and off of the surface, which increased the wear rate of the drill bit. This resonant condition is typically referred to as a motor critical speed. The analysis presented here quantifies the vibration associated with this particular critical speed problem, using novel techniques to describe resonance.

SYMBOLS

f	forcing frequency, cycles / second
f_i	natural frequency, cycles / second
k	spring constant, Newtons / meter
TR	transmissibility
x	variable displacement of a mass, meters
x_f	initial displacement from equilibrium, meters
x_{max}	maximum vibration amplitude for a mass, meters
ω	excitation force frequency, radian / second
ω_i	natural frequency , radian / second
ζ	damping factor

INTRODUCTION

The equipment that was tested is shown in Fig. 1. One purpose of the equipment was to drill shallow holes into rusted surfaces (Leishear, et. al. [1]). The drill motor and drill bit were mounted on a movable base, which rested on a stationary plate held to the wall by electromagnets. The unlubricated drill bit typically drilled 12 holes before dulling in unrusted steel plate. In rusted steel plate, only one hole was drilled, and that hole was uncertain. Several holes were required for this application.

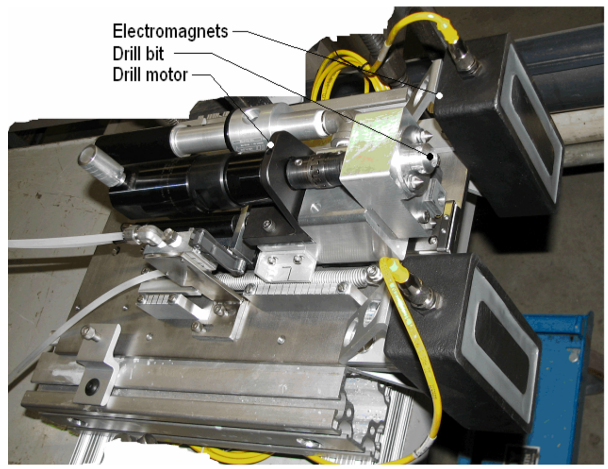

Figure 1: Drill Motor Assembly

ANALYSIS

Vibration analysis was performed to address a root cause of inadequate drilling, which was identified as drill bit chattering induced by the coupling of the resonant frequency of the spring with the critical speed of the motor. When the drill was operating, the only force to push the drill bit into the wall was the force of the spring. Since the frequency of the spring equaled the frequency of drill bit chatter, the system was resonant and drilling was ineffective.

Operating at a critical speed was clearly related to system resonance of the drill / spring system. The springs were replaced with stiffer springs, which improved drilling to improve drilling in rusted surfaces.

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With respect to the critical speed, vibration analysis clearly shows that drill bit chatter occurs. Changing the spring increased bit life during testing by reducing resonance. Fig. 2 shows vibrations for drilling a hole, where expected vibrations occur at multiples of running speed at approximately 485 rpm (cpm, cycles per minute). Of interest to chattering, vibrations at multiples of two times running speed (f = 485 rpm · 2 = 970 cpm, cycles per minute) occur, which are the result of chattering, or tapping, of the two drill bit flutes during each revolution (Fig. 3).

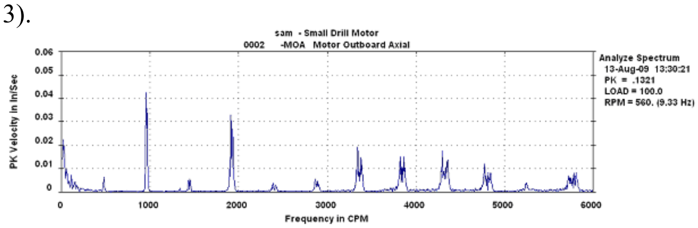

Figure2: Motor Vibration

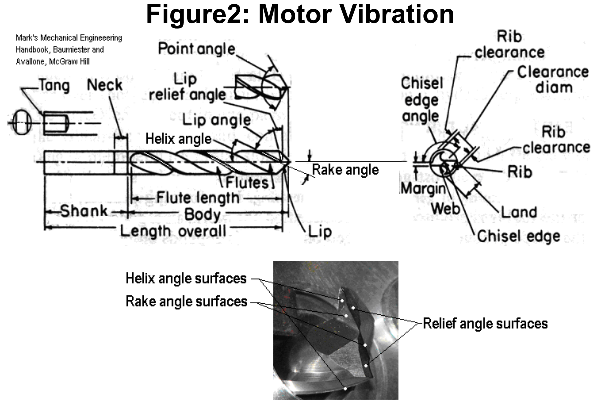

Figure 3: Drill Bit Nomenclature

To determine modal frequencies, the first mode was measured by hanging a weight on each spring, letting the weight drop, and counting the vibration cycles. First mode frequencies, f_i, were identified as approximately 120 cpm and 180 cpm for the two springs. Higher mode frequencies were calculated from f = (i) · (first mode), where i equals the mode and f equals the frequency.

The resonant condition is described by Fig. 4 (Leishear [2]). In the figure, transmissibility is shown, which is an amplification of the applied force. In this case, transmissibility shows the amplification of vibration due to chattering. The effects of replacing the spring are also shown in the figure. To use the figure, f / f_i is required, where f / f_i = critical speed / natural frequency. For the original spring, the frequency equals f / f_i = 970 / 120 = 8.08. Assume damping of ζ = 0.005, which is a typical minimum for springs. Then, the transmissibility is read directly from the figure as 56.8. This value means that any vibration at the drill bit tip is multiplied by a factor of 56.8, or more.

For the replacement spring, the relationship between the two springs was required, and this relationship was defined by the spring equation, and the transmissibility, TR, equation

$$F = -k \cdot x$$

$$TR = x_{max} \cdot k / F$$

where k is a spring constant, x is the deflection, x_{max} is the maximum deflection, and F_0 is an applied force. Using manufacturer's spring data, a ratio of spring constants is required, such that

$$\frac{k_1}{k_2} = \frac{x_1 \cdot F_2}{F_1 \cdot x_1} = \frac{5/5.75 \cdot 21.39}{6/7 \cdot 37.13} = 0.5844$$

A second transmissibility curve was generated by multiplying 0.5844 times the original spring response curve to obtain the replacement spring response curve in the figure. Using f / f_i = 970 / 180 = 5.39, the transmissibility is read directly from the figure as 56.8. Accordingly, the transmissibilty was decreased from 56.8 to 8.3; a factor of 684 %.

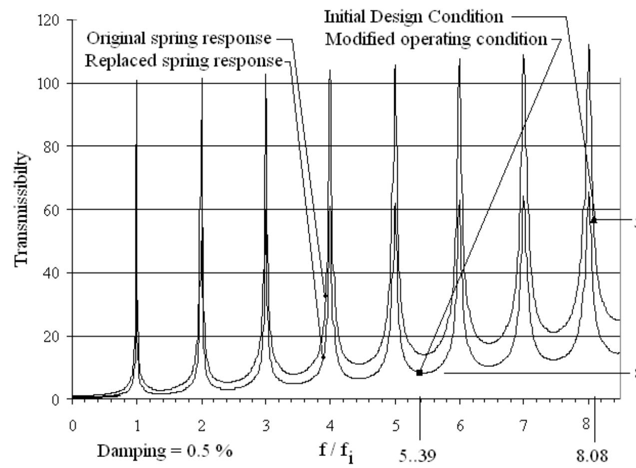

Figure 4: Sampler Resonance

CONCLUSION

In other words, the soft layer of rust permitted the start of chattering and the interaction of the chattering with the resonant spring caused the spring to resonate as observed by excessive vibrations during sampler operation. The increased drill bit surface area in contact with the material surface increased the force on the bit to initiate chattering. The spring vibration in turn exaggerated chattering and rapidly dulled the tip of the bit to reduce the number of drilled holes.

Note that resonance effects were reduced but not eliminated. Operating above the first critical speed reduces vibration, but resonance effects are not eliminated.

REFERENCES

[1] Leishear, R. A. Fowley, M. D., 2010, "Tank 18 and Tank 19 Wall Sampler Performance", Savannah River National Laboratory, Aiken, S. C., 29803, pp. 65 – 73.

[2] Leishear, R. A., 2010, "Higher Mode Frequency Effects on Resonance in Structures", ASME, Pressure Vessel and Piping Conference.