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BEARING SURVIVABILITY AND FRICTION DETERMINATION FOR FUZE DECOUPLING APPLICATIONS

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14. ABSTRACT The objective of this experiment is to find bearings that are suitable for de-spinning a fuze from a projectile body. Bearings must be able to survive both gun launch loads and high spin rates in this application. Three pairs of bearings are allowed to de-spin from approximately 250 Hz and then shot in a 155-mm air gun to simulate these loads. Overall bearing survivability and changes in friction (as measured by free spin time) are discussed in this report for three types of ball bearings. The revolutions per minute versus time plots acquired from spin-down trials provide a qualitative view of bearing performance and will allow bearing friction torque to be calculated in the future. All bearing pairs survived the loads applied. The quality of the selected bearings is evident in the spin-down profiles.			
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INTRODUCTION

The purpose of this experiment was to characterize the overall survivability and to quantify the increase in friction of three sets of bearings due to typical artillery cannon launch spin and acceleration loads. The variable sought was the change in spin-down time of the bearings, due to pure spin; air gun shots; and other factors. The spin-down times can be used in calculating the bearing friction torque, if required. For the Drag Optimized Navigation (DRAGON) program, the bearings would be used to decouple the fuze from the remainder of the body to mitigate drive actuation issues and spin-related effects on the sensor package. The three bearings tested included a generic ball bearing made by SPB USA LLC (6907), a SKF single row deep groove ball bearing (61907 C3), and a Kaydon thin section bearing with plastic cage (KAA17CL0).

BACKGROUND

A bearing is typically selected based on multiple calculated values that assumes the bearing will be spun for one million cycles (i.e., to failure). Axial and radial loads, both static and dynamic, should be considered. Bearings rated for both high bearing load and high spin conditions, and for a significantly lower number of cycles, do not widely exist. Testing bearings in high spin and high axial load applications would give a better idea of their survivability on a guided artillery round. Specifically for DRAGON, the bearings would decouple the fuze from the projectile, potentially decreasing the actuator power input. Canards would be implemented, with a slight cant angle in order to slow down the front end of the fuze. The bearing friction torque is an important factor – a high value of friction would not allow the fuze to spin-down as quickly and begin functional operation. For this experiment, a longer bearing spin-down time corresponds to decreased bearing friction.

EXPERIMENTAL SETUP

The experiment took place in an armored box located at the Environmental Test Facility, U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey. For each bearing type to be tested, two bearings were pressed and preloaded according to manufacturer specifications into a custom test cartridge. A direct current motor was mounted into a translating tube that allowed the motor shaft (with a torque feature) to spin-up the bearings in the test cartridge. Figure 1 shows a cross-section rendering of the test setup.

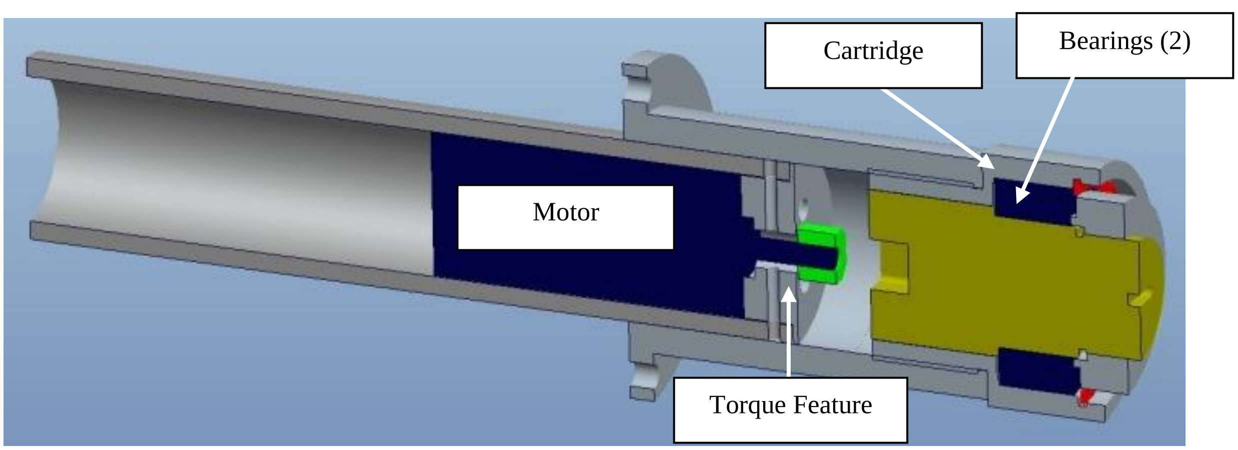

Figure 1
Cross-section of test setup

A pull cord was attached to the motor tube, allowing operators to disengage the motor from the test cartridge behind a concrete wall. An optical fiber encoder recorded the revolutions of the bearings. A powered limit switch allowed the data acquisition team to know the precise time when the motor was disengaged and the bearings were de-spinning due to their own friction. Encoder output, along with the high-low transition of the limit switch was collected in MATLAB and reduced to revolutions per minute (RPM) versus time plots. During the trials, an oscilloscope provided a live reading of the spin rate from the square wave output of the encoder. A handheld infrared thermometer was used to periodically check the temperature of the bearing cartridge and drive motor housing. Figure 2 shows the actual experimental setup from the exterior of the armored box.

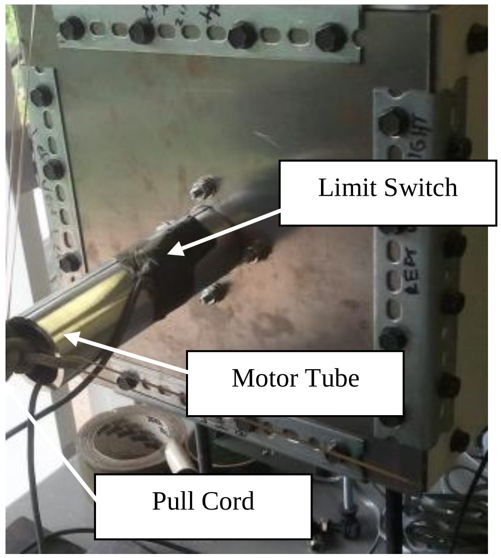

Figure 2
Outside of box, various components displayed

TESTING CONDITIONS

Each bearing pair was initially spun to a target steady-state speed of 250 Hz (or to the maximum operational power input of the motor). After spinning the bearings at steady-state for approximately 30 sec, the bearings spun down inside the cartridge. This process was repeated for up to nine trials. Each bearing pair was then extracted from their spin cartridge and pressed into a custom rig to shoot them once in a 155-mm air gun (non-spinning round). Then, the bearings were pressed back into their original spin cartridges and spun for another set of up to 12 trials. All spin trials were conducted at ambient conditions (approximately 80°F). The experimental process is summarized next.

Bearings from Supplier

Condition A

Spin-Up:

Planned runs per bearing pair: 5
Maximum speed to be driven: 15000 RPM (250 Hz)
Time at maximum speed: 30 sec

Condition B

Air gun shots:

Shots per pair: 1
Setback acceleration: approximately 14,000 g's

Condition C

Spin-Up, post-air gun:

Planned runs per bearing pair: 5
Maximum speed to be driven: 15000 RPM (250 Hz)
Time at maximum speed: 30 sec

Condition D

RESULTS

Bearing survivability under projectile spin rates and gun launch accelerations is critical for fuze decoupling. After the experiment was complete, all of the bearings were operational. Each bearing pair spun freely by hand, and there was no visible damage to the cages. It is critical that the bearings survive the loading cases applied during this experiment since they serve as a preliminary indicator of how the bearings would survive under projectile gun launch and flight. The quality of the selected bearings is clearly visible in figure 3. The generic ball bearings have the greatest friction out of the box (least spin-down time).

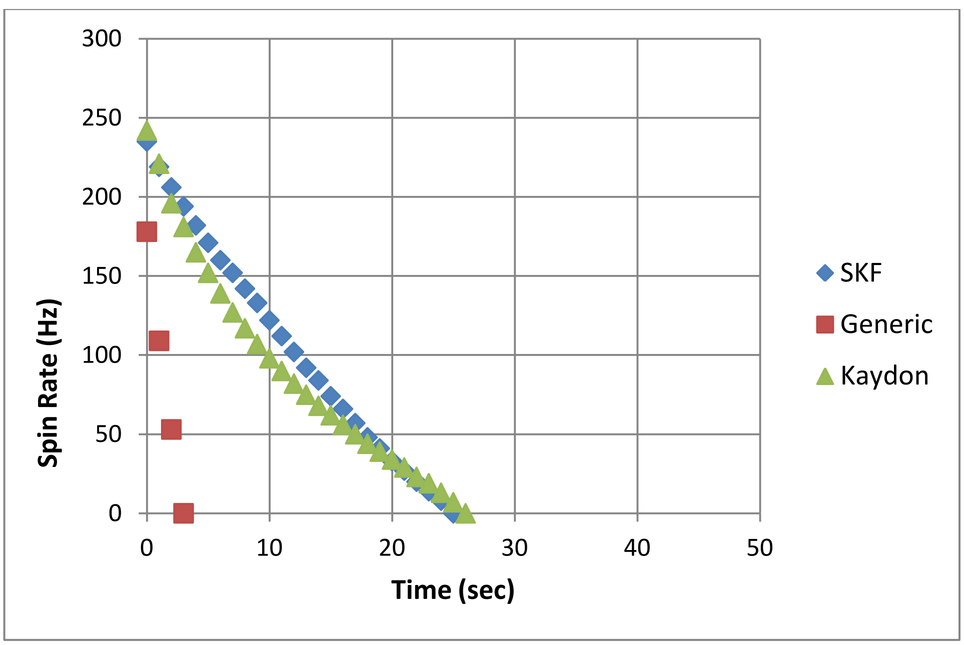

Figure 3
Spin rate versus time for the initial spin-down trial directly from supplier (condition A)

After running the bearings for six to nine trials, the bearings “break-in” and spin friction decreases. For example, the generic ball bearings experience a spin-down time increase of 330% after nine spin-down trails. The spin-down time increases after the first set of spin trials and is clearly shown in figure 4.

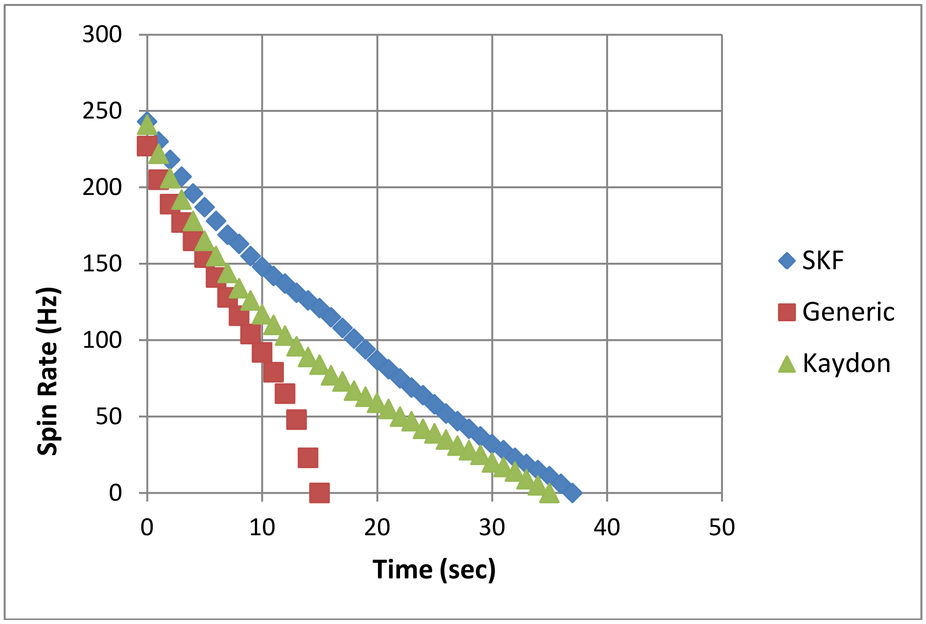

Figure 4
Spin rate versus time for the last spin-down trial prior to air gun shot (condition B)

By subjecting the bearings to air gun loads, it was expected that there would be a decrease in spin-down time due to degradation of the races. Figure 5 shows the decrease in spin-down time due to effective increase in friction from air gun loading.

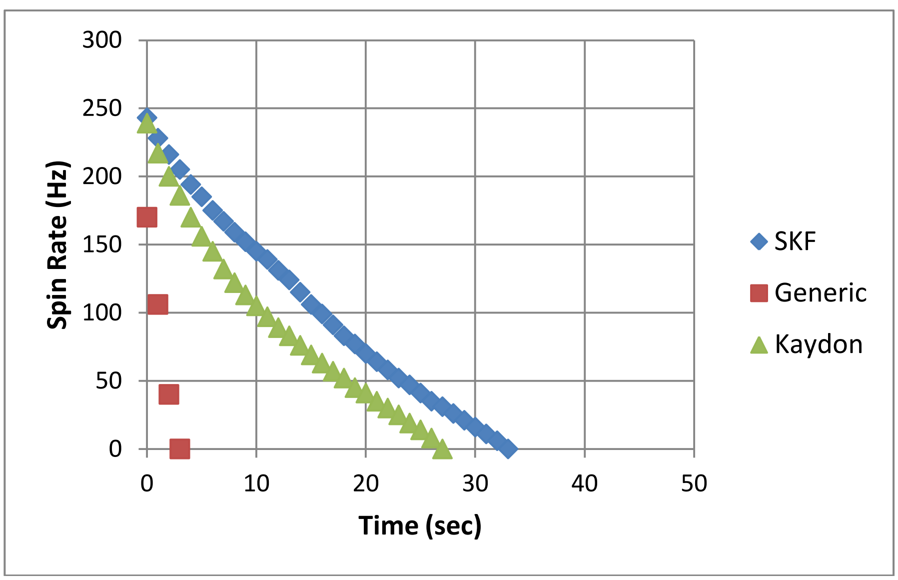

Figure 5
Spin rate versus time for the initial spin-down trial after air gun (condition C)

The generic ball bearings experienced the greatest decrease in spin-down time due to air gun loads. In contrast, the SKF and Kaydon bearings had only a minor decrease in spin-down time and thus will perform better when subjected to gun launch setback loads. The effects of the air gun were only present for the few spin-down trials immediately after shooting. Figure 6 depicts the spin-down profile for the bearing pairs after a single air gun shot and the second round of spin-down tests.

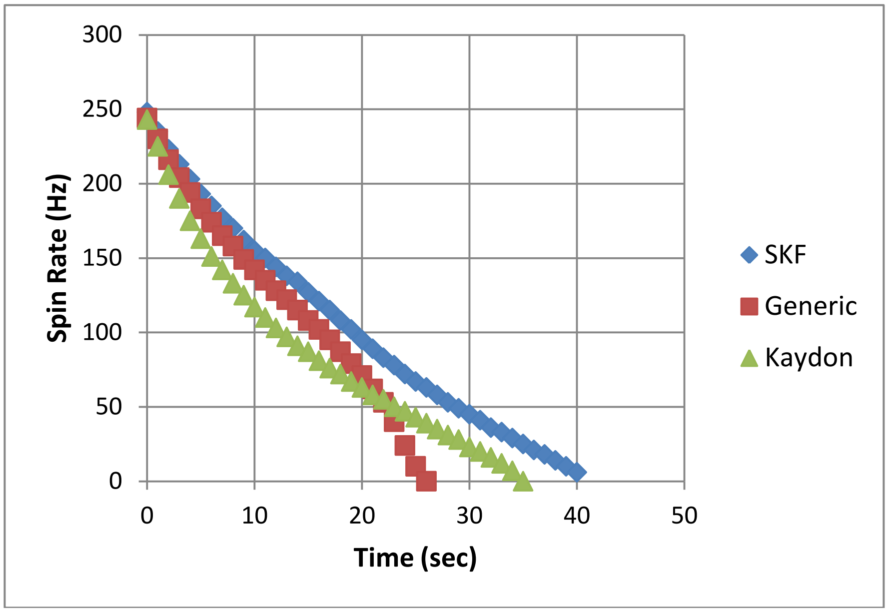

Figure 6
Spin rate versus time for the final spin-down trial after air gun (condition D)

One of the main objectives of this experiment was to determine representative spin-down times to eventually estimate bearing friction. Break-in has to be considered in this decision. In almost all spin-down trials, the bearings continually spun for a longer duration as compared to the previous trial. However, the law of diminishing returns applies, and the bearings spin-down times began to converge for sequential trials. Break-in is highly undesirable in a production setting where resources are not readily available to break-in off-the-shelf components prior to assembly. The final spin trial of each bearing pair provides the optimal spin-down time with respect to break-in. In addition, the representative times must be calculated from the post-air gun trial set since the bearings will be subjected to setback loads in operation. As a result, the final spin-down time post-air gun will be the representative for future friction torque calculations. The times are summarized in table 1.

Table 1
Spin-down times for friction determination (final trial, post-air gun)

Bearing set	Spin-down time (sec)
SKF	41.6
Generic	26.6
Kaydon	35.5

For the purpose of calculating the frictional torque of the bearings, the moment of inertia of the material pressed into the inside race of the SKF and generic bearings is 3.48E-04 lbf-s^2/in.-in.^{2}. The moment of inertia for the Kaydon bearing load is 3.49E-04 lbf-s^2/in.-in.^{2}.

CONCLUSIONS

The two main objectives of this experiment were to determine if the bearings would survive projectile spin loads and setback loads and to characterize the changes in spin-down profiles due to these loads. In terms of survivability, the results showed no degradation in performance due to spin. Air gun loads only had a temporary degradation effect on the bearing friction as compared to their state prior to air gunning. At the end of the second set of spin trials, all three bearing sets had spin-down times at or greater than their times immediately before air gunning. Visual observations of the bearings showed no damage after all trials were complete. In terms of optimal spin profile, the generic ball bearings have the least desirable performance characteristics. They have the greatest friction out of the box and at the end of the spin trials (pre and post-air gun). Also, unlike the SKF and Kaydon bearings, the generic ball bearings experienced a significant increase in friction after being subjected to air gun loads. The SKF and Kaydon bearings have similar desirable performance characteristics. If a thin-section bearing is required for the decoupling mechanism, then the Kaydon bearing should be considered. Otherwise, the SKF bearing is more likely to survive when exceeding specification spin rates (since it has a metal cage) and should be considered. Future work should entail subjecting the bearings to combined loading (i.e., applying axial, radial, and spin loads simultaneously) and testing multiple manufacturing lots of bearings. It may also be desirable to take thermal effects into account to represent changes in temperature of the mechanical assembly during flight.

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