Advancements in Ball Bearings Used for Critical High Tech Applications

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Balls are one of the oldest mechanical devices, being found in bearings used on Roman ships constructed around 40 A.D. Yet new designs, manufacturing techniques and applications are continually being developed for precision balls. For example, hollow balls used in ball transfer units in the cargo section of airplanes are reducing weight and fuel consumption. Stainless steel balls used in mechanical airbag sensors have been used in millions of vehicles without a single failure to deploy or accidental deployment caused by the sensor. Improvements in manufacturing techniques for miniature balls have helped to meet the demanding requirements of manufacturers of disk drives, dental drills, satellite guidance systems and other critical applications.

Saving weight in airplanes

Long before the recent hike in fuel prices, the air cargo industry was looking for ways to reduce weight to save fuel. The air cargo bay that carries freight within industry standard containers know as unit load devices (ULDs) was one area that was targeted. Ball transfer units (BTUs) are used to enable load handling personnel to rapidly load, position and unload ULDs within the cargo bay. BTUs consist of cases containing balls that protrude upward to contact the bottom surface of a ULD. Typically 1 inch diameter balls are used with the top tangent point of the ball positioned 0.25 inches above the top skin of the panel. The solid 1 inch balls weigh 67 grams. These balls are typically supported within the case by a race of 1/8 inch balls enclosed in a housing.

Ball transfer units are arrayed in housings to construct ball panels that are used to line the cargo surfaces of airplanes. A larger airplane has tens of thousands of balls in its cargo bay, generating a substantial amount of weight. Ball producers were asked if they could produce balls that were substantially lower in weight while still being able to withstand the 6,000 pound crush loads. The solution was to produce a hollow ball bearing by stamping two semi spheres from 440 stainless steel and welding them together.

The biggest challenge was the welding operation, in which the two halves of the bearing have to be lined up perfectly and then bonded together to withstand loading and prevent leakage. After the balls are welded, they are flashed to remove the weld band, soft ground, heat treated and hard ground to precision tolerances. Balls that require moderate levels of precision are then tumbled in a barrel, cleaned and passivated to provide corrosion resistance. Higher precision balls are lapped and then cleaned and passivated. The heat treating process has been refined to increase the surface hardness of the balls to avoid marks and indentations and provide longer life.

The hollow ball weights only 21 grams, providing a savings of 47 grams or about 0.1 pounds for each ball. This represents a 69% weight reduction compared to the original solid design. As an example, a C-130H Hercules military transport has cargo bay dimensions of 36 feet long by 9 feet wide resulting in a floor space of 324 square foot. The ball panels used to cover the floor have approximately 40,000 balls, resulting in a weight savings of approximately 4,000 pounds when hollow balls are used. Typical benchmarks for fuel savings for a specified weight reduction are about 0.0036 gallons/pound/per hour. So, based on 2,000 annual flight hours, reducing weight by 4,000 pounds will save approximately 28,800 gallons of fuel per year. This represents a savings of approximately $43,200 per year per aircraft at current jet fuel prices. Hollow balls have also been applied to other applications such as flow valves that require a ball that is both light and magnetic.

Improving automobile safety

Mechanical airbag sensors represent another critical application. A hollow tube in the sensor is used to guide a ball. The ball is held in place by a spring at the open end of the tube. When the sensor is assembled, this spring is initially displaced by the ball which creates a preload. The sensor is designed to trigger when a sudden deceleration of the vehicle causes the ball to suddenly accelerate out of the tube. The ball overcomes the preload on the spring and displaces the spring until it contacts a second spring placed in its path. When the first spring contacts the second spring, an electric circuit is completed that triggers the operation of the airbag.

What makes the application difficult is that the ball has to maintain the same clearance with the tube over the wide range of temperatures in which vehicles are used. The stainless steel material for the tube was selected first so the challenge for the ball manufacturer was to find a ball material to provide the same coefficient of thermal expansion. The one material that was found with the right coefficient was stainless steel type 431. But no one had ever made a ball out of 431 stainless, much less one with the close tolerances required in this application. The ball requires a spherical tolerance of 0.000010 inch, a size variation of +/- 0.000010 inch and a surface finish of under Ra 1.

These tolerances would not be that difficult to meet with a hard material like 52100 chrome or 440C stainless, both of which have a Rockwell C hardness in the 60s. But 431 stainless has a Rockwell C hardness of only about 40. The tendency of the material to deform as it is processed makes it much more difficult to achieve these tolerances. The ball was produced by first performing a cold heading operation on a coil of wire. The result is a ball that looks like the planet Saturn, with a ring around its middle made up of material that was forced between the two halves of the die. This ring is removed by a machine called a flasher.

The next step is heat treatment, which includes cryogenic freezing and tempering. The balls are then ground, finish lapped, cleaned and passivated. Finally, gold plating is applied to provide further corrosion resistance for these critical components. Mechanical airbag sensors have been largely superseded by microelectromechanical devices, however, their record of protecting the occupants of tens of millions of vehicles without a single recorded failure has never been matched.

Making miniature balls to high tolerances

Major improvements have also been seen in the manufacture of miniature balls that are used in many types of computer storage equipment, medical and dental devices, aerospace equipment, precision machinery, laboratory instruments, as a vent release in lithium ion batteries, and many other types of sophisticated devices. While larger balls are headed into a ball, miniature balls smaller than 1/16 inch are slugged or chopped from wire. First, the wire is carefully inspected for size, surface finish and surface and internal integrity. The wire is then cut or slugged into cylinders in an operation that typically produces 100,000 pieces per hour.

The parts are then placed in a flasher where they ride in grooves between the faces of two cast iron disks. The inside of the grooves are rough, which tears the flash off of the balls. One wheel rotates and the other is stationary. The stationary wheel has an opening so that the balls can be fed into and taken out of the grooves. A special conveyor feeds balls into one hole. The balls then rattle around the groove and come out the other hole. They are then fed back into the conveyor for repetitive trips through the wheel grooves. The process continues until the balls are fairly round, just larger than the proper size and the flash is completely gone. Stock removal in the flasher is approximately 0.006 inch, varying with the size of the ball. The balls are left oversize so that they can be ground to their finished size after heat treatment.

After flashing, the balls move to a ball grinding machine where they are soft ground. Stock removal in this operation is typically 0.008 inch to 0.010 inch. The grinding or lapping machines have one stationary and one rotating wheel or plate. Following soft grind, the balls are cleaned and dried and then put through a roll grading operation. The roll grader consists of precision rotating rolls positioned so that balls of the correct size pass between the rollers while those that are too large or too small drop out. The balls are then heat treated to ensure proper hardness and reduce retained austenite or to meet special requirements.

The next operation after heat treating is hard grinding. Stock removal in this operation is approximately 0.006 inches. Then comes another series of cleaning, drying and roll grading steps. Rough lapping removes around 0.0006 inch and improves the sphericity to at last 25 millionths and in most cases to 10 millionths. A screening or another roll grade depending on the size of the ball is preformed. Finish lap is a light polishing operation that removes 0.0002 inch of stock and improves the sphericity to 3 to 5 millionths. If a stainless steel ball is being produced, barrel cleaning and passivation is then performed before proceeding to a centrifuge dry and then onto final inspection and gauging.

Most equipment that needs to move uses balls. Precision high tech applications like the ones described here often need balls that meet special requirements such as low weight, small size and close tolerances. The design and manufacturing of these balls demands creative engineering and meticulous attention to detail. The end product is a high quality, high tolerance product that meets the requirements of the application.