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FEATURE IMPROVEMENT AND COST REDUCTION OF BAITCASTING FISHING REELS FOR EMERGING MARKETS

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ABSTRACT

Baitcasting fishing reels are a challenging product to sell to new users in emerging markets. Their complex and less-than-intuitive design make them poor candidates for a novice fisherman selecting his or her first fishing reel. Based upon manufacturer constraints and design requirements, our team lowered the price point and improved the usability of the Okuma Cerros baitcasting fishing reel to make it more appealing to a wider range of consumers, especially in emerging markets. This project resulted in a three-phase redesign: reducing cost via alternative materials and replacing bearings with bushings; prototyping a simplified cast control system; and proposing an improved user interface.

1. INTRODUCTION

This project was done in conjunction with Okuma Fishing, a fishing rod and reel manufacturer. The original project statement provided by Okuma was to develop a lower cost baitcasting reel, basing it off of its current Cerros reel. This goal originated because of an assumption that most fishermen will choose to buy a spinning reel over a baitcasting reel as spinning reels are perceived to deliver higher quality for a lesser cost [1]. Emerging markets, such as Brazil, provide significant opportunity for Okuma to expand its product line. Brazil has a diverse recreation and sport fishing sector rapidly growing at an estimated thirty percent per year [2]. After consulting with a wide range of fishermen, it became apparent that potential customers in these markets, many of whom possess only a basic knowledge of fishing, will choose to purchase spinning reels over baitcasting reels. This is due to their simple design, shallow learning curve, and wide range of uses. Additionally, it was revealed that spinning reels and baitcasting reels have intended differences and separate uses. Thus, the overarching goal of this project became the development of a baitcasting reel that is both more cost-effective and user-friendly so that a typical fisherman will choose to purchase a baitcasting reel in addition to a spinning reel.

Table 1 - Spinning and baitcasting reel comparison

	Spinning Reel	Baitcasting Reel
Usability	Easy to Learn and Use	Steep Learning Curve
Spool	Vertical/Stationary	Horizontal/Rotating
Mounting	Below Rod	Top of Rod
Casting	Simple	More Accurate/Versatile
Purpose	Light Tackle / All Around	Heavier Tackle and Fishing in Cover
Perception	Standard	"Pro" or "Bassfisher"
Value/Quality	High Quality for Low Price	More Expensive for Same Perceived Quality
Bottom Line	Go-To, All Around Setup	Fishing in Cover and with Big Lures

While spinning reels appeal to beginner and intermediate anglers because of their more user-friendly design, lower price, and wider range of uses, both reel types are designed to serve different functions. A comparison can be seen in Table 1. Spinning reels require lighter line and are therefore used in situations necessitating lighter tackle or for angling in locations without obstructions in the water. Baitcasters, on the other hand, enable the angler to use heavier weight line and lures. This is particularly useful when casting into weeds or in instances where an angler must force a fish out from cover. Such cases are not to be underestimated as fish prefer areas of heavy cover and baitcasters permit fishermen to cast closer to fish. Because of their unique capability, serious fishermen often carry several baitcasters' reels in addition to spinning reels.

The most important difference between the two types of reels is in the spool design. On a baitcasting reel, which can be seen in Figure 1A, the spool axis is horizontal and rotates to play line out during a cast. On a spinning reel, shown in Figure 1B, the spool axis is parallel to the rod and remains stationary; therefore, line uncoils itself during a cast.

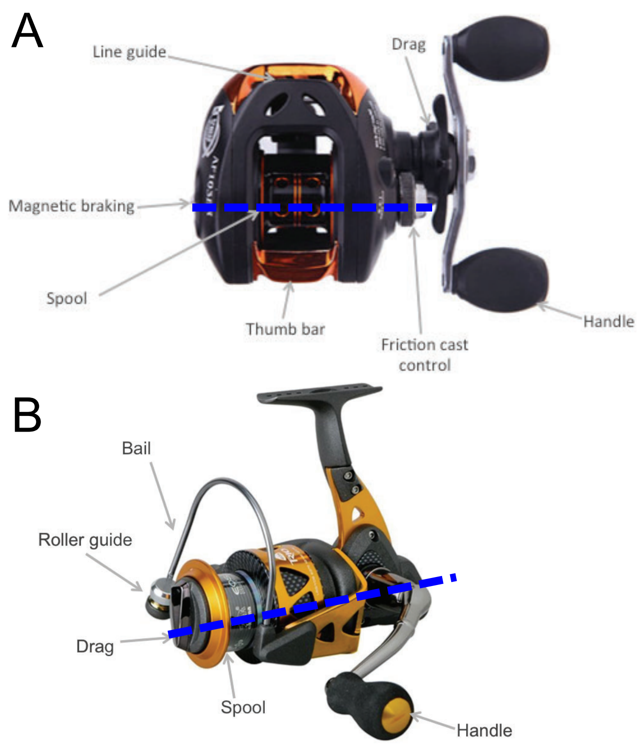

Figure 1 –Nomenclature for A) baitcasting reel, and B) spinning reel. Axes of rotation are marked in blue.

Because the entire spool rotates during the cast, it builds up rotational momentum that causes it to continue to rotate at higher speeds even after the lure has slowed or hit the water. This is problematic and will form a large knot of line in the reel that is referred to as 'backlashing' or a 'bird nest', as seen in Figure 2. To prevent this, baitcasting reels incorporate friction and braking features, called cast-control, to prevent over-rotation. They also require a specific casting technique whereby the angler uses his thumb to monitor the outgoing line and can apply friction directly to it if need be. Despite cast control, backlashing remains a frustration for all beginning baitcaster fisherman who have not yet mastered the technique of using the thumb to supplement the cast control features. And, it is this frustration that more experienced anglers believe drives average-skilled fishermen to purchase spinning reels rather than baitcasters.

Figure 2 - A "bird's nest" resulting from poor cast control

2. DESIGN AND ANALYSIS OF SYSTEMS

2.1. COST

Okuma identified the two most expensive components for cost reduction analysis: the ball bearings, and the brass gears in the drive train. As shown highlighted in red in Figure 3, the current Cerros reel contains ten ball bearings.

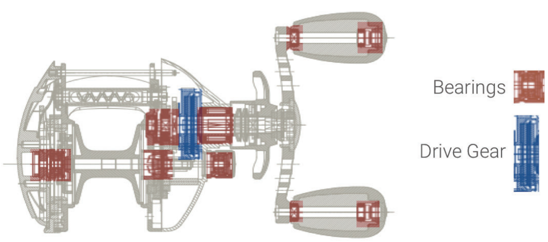

Figure 3 - Cross section of the Okuma Cerros reel

Many of them are redundant and only included because users associate more ball bearings with higher quality [3]. Using proper mounting, lubrication, and material selection, the same performance can be obtained with bushings.

2.2 Cast Control – Friction and Magnetic

The best method of cast control is for an angler to use his thumb to control the speed of the spool on a cast. However, most novice fishermen do not know to do this, which leads to the "bird's nests".

To help combat the angular momentum of the spool and reduce the dependence on using a thumb, two types of cast control mechanisms are commonly used in baitcasting reels. The first, which maintains a constant force during the cast, is friction cast control. It is adjusted by rotating a small knob near the reel handle. As this knob, which has about 810^{o} of rotation, is screwed tighter it applies an increasing normal force to the end of the spindle that increases frictional torque. The second type of cast control is accomplished with either a magnetic or centrifugal brake located on the side of the spool opposite the reel handle. While the first type of frictional cast control provides a constant force throughout the cast, this second type is a ‘viscous’ cast control that provides higher braking forces during times of faster angular velocity. Centrifugal brake control is more complex and thus less common among low and mid-range reels. Therefore this analysis focused entirely on magnetic braking.

Magnetic braking functions by utilizing the eddy currents produced when a conductive metal (the spool) rotates through a magnetic field. The rotation creates electric currents that, by Lenz’s Law, have magnetic fields opposing the field originally induced [4]. This opposing force can be manipulated via adjustments in distances of the magnets from the rotating spool and thus used to slow the speed of spool rotation. The baitcasting reel modified for this study has an internal mechanism with five cylindrical magnets and a range of separation of 2.3 to 4.8 millimeters from the spool. A schematic of this setup is shown in Figure 4. Magnet distance is adjusted externally via a round dial on the reel casing turned by the angler. Numbers are printed on the casing around the dial to provide a gauge for the angler. Figure 5 depicts the cast control braking forces observed at various spool rotational speeds. Note that the frictional cast control is a constant braking force (at each setting) while the magnetic braking effect increases with spool speed.

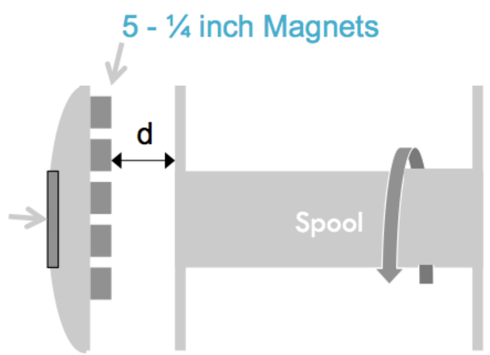

Figure 4 – Schematic of magnetic braking system of the Cerros reel. There are five magnets that rest a distance d from the spool, which can be adjusted using a dial on the outside of the reel. The closer the magnets are, the stronger the magnetic damping force is.

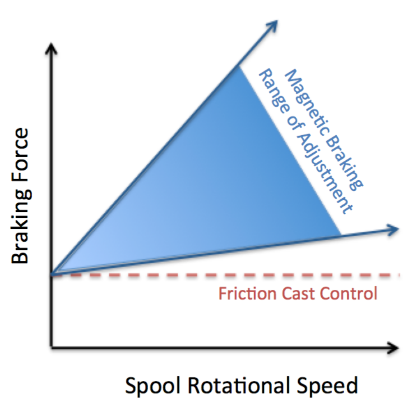

Figure 5 - Friction and braking forces on spool during cast

2.3. User Interface

There are two aspects of a baitcaster with which the user interacts directly: the thumb bar and the retrieve (or handle), both of which highly impact its usability. The purpose of the thumb bar is to disengage the spool so it can freely rotate during the cast, allowing line to exit through the line guide. Once the cast is complete and the angler starts to crank the handle, the thumb bar engages so the spool cannot freely rotate in reverse. On the current reel design, the thumb bar is 29 mm wide, 8 mm deep, and has a matte texture where the thumb is supposed to be placed. It is also meant to position the user’s thumb near the line so that during the cast, the angler can use thumb pressure applied to the spool to control the speed of its rotation.

After the cast, the retrieve hand is used to turn the reel handle and disengage the thumb bar. Once the thumb bar is disengaged, the spool cannot spin freely and line can only be pulled out if it overcomes the drag force of the reel (set by the angler). Although there are left-handed and right-handed reels, the naming convention is counterintuitive as a right-handed reel requires the user to fight fish by holding the rod in his left hand. Additionally, anglers cast while holding the rod in their dominant hand, so if a fisherman uses a right-handed reel and is right-hand dominant, he would have to cast with his right hand, then switch hands in order to use the handle on the right side, fighting the fish with the rod in his non-dominant left hand. This action can be seen in Figure 6. This switching of hands between casting and reeling is a source of complaint for many anglers, and has led to a shift in which some right-handed anglers have begun to buy left-handed reels and vice versa.

Figure 6 - Switching rod hands from cast to retrieve

3. SUMMARY OF OBJECTIVES/CONSTRAINTS

As previously mentioned, the overarching objective of this project was to make the Cerros reel cheaper and more user-friendly. This was accomplished in three phases: (1) reduce cost by changing bearings to bushings and altering materials of the main drive gear; (2) simplify both the friction and braking components of the cast control; and (3) adjust the thumb interface and retrieve to improve usability. These improvements can be seen visually in Figure 7. However, it is also necessary to maintain certain aspects of the reel. Table 2 lists the current specifications and the new design's requirements. It should be noted that while the team used these criteria to drive the redesign, because marketing is such a significant component of the actual selling process, certain modifications may ultimately not be used if Okuma believes they will infringe upon the reel's marketability.

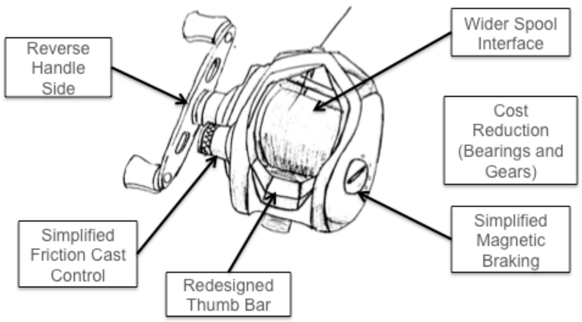

Figure 7 – Design change modules

Table 2 - Reel design specifications

	Original Reel	Design Req.	Proposed Prototype
Cost	$100	≤ $50	~ $75
Weight	7.9 oz	≤ 7.9 oz	~ 7.9 oz
Cast control and braking	Complex	Simplified	Simplified
Intuitive UI	No	Yes	Yes

4. OVERVIEW OF DESIGN CHANGES

4.1. Cost

Functional requirements were established for the bushings to ensure they would have a performance under loading similar to the existing ball bearings. Thus, each bushing had to hold 12 lbs load at 3000 RPM (which is the maximum load and speed the reel is currently designed to experience) and be able to operate smoothly at those high rotational speeds.

It was found that the highest loaded and fastest turning bearing, a spool bearing, if switched to a bushing would have a maximum pressure of 200 psi and maximum velocity of about 100 surface feet per minute. Therefore, the maximum PV value of the bushing would be 20,000. As the PV values of low-end bronze bushings are around 75,000, this bushing has ample safety factor. Bronze is also a good material in this application because it can be impregnated with other materials, such as oil, to make it self-lubricating, thereby increasing life and reducing required maintenance for the user [5]. Also, if the PV rating ever did exceed the material's maximum allowable, it would only be for a very brief amount of time, thus having very little effect on the overall life of the bushing.

There are two other spindle bearings that support a small pinion gear inside the main body of the reel. The gear is made of brass and it was decided switching to bushings would generate high frictional forces, creating an undesired restrictive torque in the reel because the bronze and brass are not complimentary materials for sliding contact bearings. Thus it was determined that for the prototype reel, bushings could replace three ball bearings: the single spool bearing, and both ball bearings that support the handle shaft, as shown in Figure 3. According to Okuma, these modifications can save the consumer between $15 and $20. The main drive gear, highlighted in blue in Figure 3, was the second high-cost component. It is quite heavy and large relative to the other parts and is machined from a single piece of brass. It is connected to the handle and drives a smaller brass pinion that connects to the spool. A simplified version of the internal drive train in the Cerros reel is shown in Figure 8.

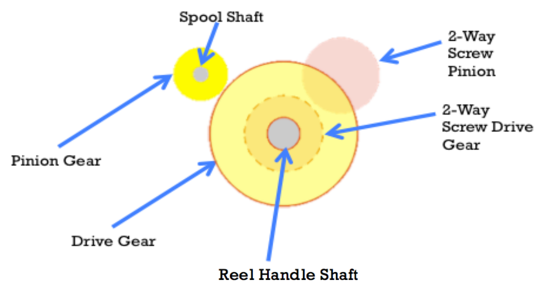

Figure 8 – Simplified version of internal drive train

The drive gear is an irregular helical gear due to the helical angle of its teeth and its fine tooth size. It is designed to take higher loads than a spur gear because it has more than a single tooth in contact with the pinion, thus providing smoother motion for the user.

In modifying material of the gear, functional requirements were also established. It had to: hold nine in-lbs of torque and maintain the same geometry as the current gear except for the thickness. To determine what materials were acceptable, a free body diagram was done of the spool, shown in Figure 9, to evaluate the torque a new gear would have to resist. In order to get a conservative first order analysis of the bending shear stresses and bending stresses inside the gear, the gear was treated as a spur gear.

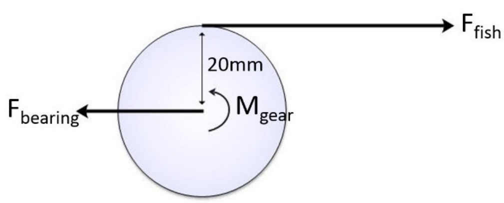

Figure 9 – Reel free body diagram

Using the dimensions of the current drive gear tooth, the bending shear stress in an equivalent spur gear tooth is about 3,500 psi, and the bending stress is around 6,000 psi. A high strength plastic like nylon mc901 has a tensile yield strength of about 12,000 psi. In order for a gear not to fail under loading, the bending shear stress must be less than roughly half the tensile yield strength [6]. Since this gear can experience impulse loads, a higher safety factor would be more optimal to ensure the user does not continually break gears. By increasing the width of the gear by thirty percent, the stresses are decreased by thirty percent. Due to the conservative nature of the spur gear analysis, the actual stresses are lower than the calculated ones; thus, it is viable for an injection molded plastic gear to be used. By producing the gear in a different material, the manufacturing cost of the reel can be reduced.

4.2 Cast Control – Friction and Magnetic

Currently, the two cast control mechanisms present multiple options and increase the reel's complexity. The "simplified cast control" system incorporates changes to both the friction and magnetic components and makes the setting of both more intuitive for the user. The friction cast control is currently difficult to adjust due to its proximity to the star-shaped drag adjuster and lacks any indicator showing to what extent it is engaged. To improve this our team redesigned the knob, which can be see in Figure 10. To help determine the amount of engagement, the knob will only have approximately 400° of rotation, which when coupled with the thumb-tab, permits the user to know how much friction is being applied.

Figure 10 - Rendering of redesigned cast control knob

The magnetic braking system currently has eleven depth settings, ranging from zero (minimal braking) to ten (maximum braking). As this presents a wide range of potential settings, our team ran tests in a controlled environment to identify which magnetic settings affected the spool's deceleration. For these tests, the reel was fastened to a stiff dowel secured to a table to simulate a rod, as shown in Figure 11. A weighted lure was attached to the end of the line and dropped from a known height. After the lure hit the ground, the number of spool revolutions and the time it took to stop were measured. This process was repeated for a series of cast control settings. As the magnetic braking was increased, the deceleration of the spool also increased, resulting in fewer rotations of the spool and less bird's nesting, as shown in Figure 12.

Figure 13, captured during the testing, shows the formation of a bird's nest due to spool over-rotation after the tension has been removed from the line.

Tests were also run for various magnet orientations in order to determine if alternate designs for magnet location were possible. These tests, however, proved that the current 90° orientation between the magnets and the spool is optimal as it exposes the largest surface area of the magnets to the spinning spool, thereby increasing the eddy current, and allowing fewer rotations after the lure hits the ground.

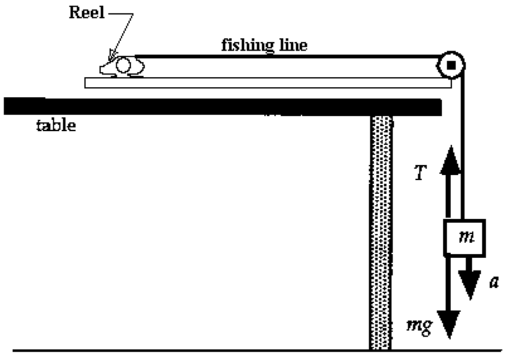

Figure 11 - Magnetic braking bench test set-up

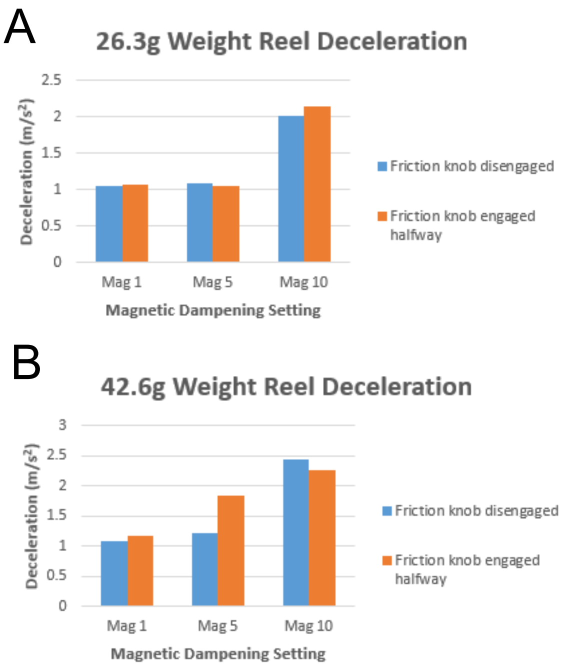

Figure 12 – Magnetic braking deceleration data for A) a 26.3g weight, and B) a 42.6g weight.

Figure 13 - Bird's nest formation

For the lighter lure weights, typical of what an angler would use, there was negligible difference between a magnetic braking setting of one and five, as shown in Figure 12. This led to the conclusion that there are too many settings for the magnetic braking, especially for the novice user.

To address this issue, a simplified cast control mechanism was designed (Figure 14). The dial mechanism was removed entirely and replaced by a simplified one-piece side plate with integrated adjustment steps. This design change reduces the number of parts in the side plate from thirteen to two, allowing for faster manufacturing and easier assembly. There are three metal strips in the integrated side plate design, and their heights are based upon the settings of one, five and ten from the initial dial mechanism. To switch between settings, the user removes the side plate from the reel and moves a band of magnets to the desired metal strip. One downside to this design is that the user must remove the side plate to adjust the magnetic braking setting, but since reels with centrifugal braking systems also require users to remove the side plate to adjust the braking, our team concluded that this drawback would be acceptable in the fishing community.

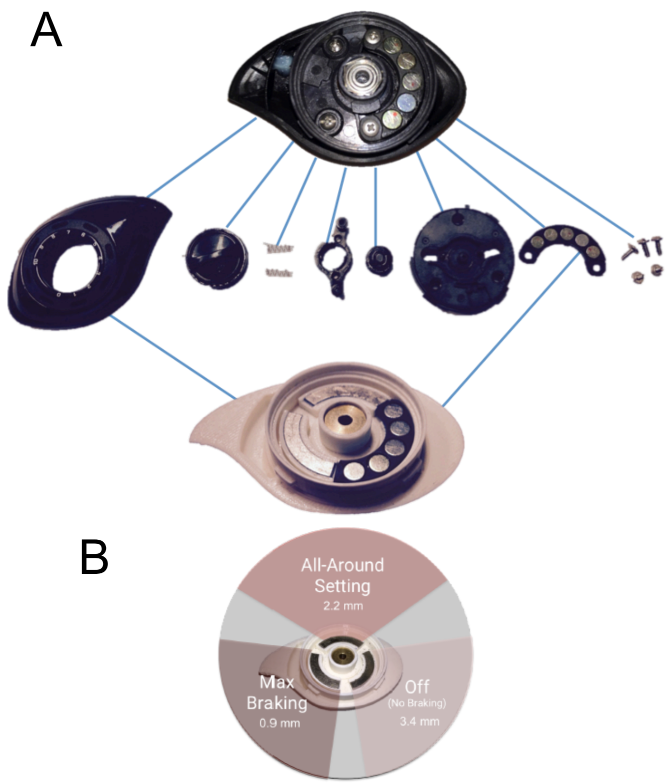

Figure 14 – Simplified cast control and housing. Inset A shows a comparison of original to new design, highlighting part number reduction. Inset B shows the three distinct settings achieved by moving a band of magnets between the three strips.

4.3. User Interface

The final part of the design changes consists of altering the user interface to make it more intuitive for novice anglers. Though it was out of the scope of this project to create a functional prototype, test it with users, and iterate to reach the optimal design, the team devised a set of suggestions for design changes to be implemented in the future and optimized via user feedback.

To assess the current reel's usability and identify what areas of the user interface to target, the reel was mounted on a rod and given to people who had no fishing experience. Each subject was asked to hold the rod in whatever way felt most natural. In these tests, subjects either placed their thumb on the rod such that it did not touch the reel at all, or they placed the tip of their thumb on the thumb bar, as shown in Figure 15A. However, as mentioned in Section 2.3, correct use of the reel dictates that the user place her thumb on the line to control the rate at which line leaves the spool during the cast (Figure 15B). When asked why she had not placed her thumb on the line, one subject said that "it is a spinning mechanism and we're taught from an early age not to touch moving parts". Therefore, the first suggested design change is to improve the user interface with a more usable thumb bar that makes it intuitive for users to place their thumbs on it.

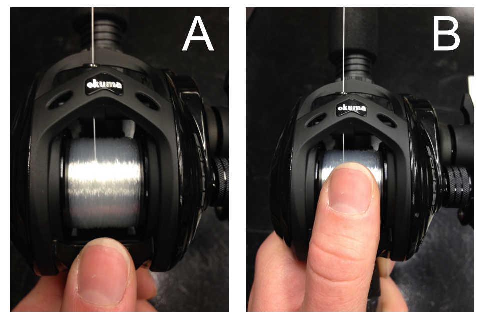

Figure 15 – Thumb placement on spool. Inset A shows the intuitive placement that non-fishers used when asked to hold the reel; inset B shows the correct placement for baitcasting.

There are three modifications to the thumb bar that will achieve this goal. The first involves a geometry change to the reel profile that will recede the thumb bar and make the spool more prominent. There is currently extra material at the end of the reel profile near the thumb bar, which serves a purely aesthetic purpose. If that 1-3 mm of material were removed, the thumb bar could be lowered, making the spool more conspicuous and thus more inviting to a user's thumb. The second change involves adding a visual cue to the thumb bar, such as the bottom part of a thumbprint, that would suggest to the user what part of his thumb should rest on the bar. The third suggestion is to increase the spool width (and thus the interface width) by about 2 mm. This will make the whole interface more inviting to a user, especially one with larger thumbs. Additionally, for the same amount of line, a wider spool results in a smaller moment of inertia for the spool and line together. Therefore, this third design change could also help reduce bird's nesting in the reel, which would make beginners more likely to purchase it.

The second suggestion for user interface improvement involves rebranding the retrieve on the reel. As mentioned in Section 2.3, current reel nomenclature causes right-handed anglers who buy right-handed reels to have to switch the rod from their right hand to their left between casting and reeling in the line. This is different from spinning reels, which have reversible retrieves that can be set to either the left or right side so the angler does not have to switch hands. As Okuma hopes to market the modified Cerros reel to the entry-level fisherman who would normally buy only a spinning reel, it will likely decrease the learning curve if a right-handed baitcaster allows a right-handed fisherman to keep his dominant hand on the rod. Thus, a marketing strategy in which rods currently labeled as left-handed are rebranded as right-handed, and vice versa, could attract more novice users.

5. TESTING AND RESULTS

In order to see how the bushings would perform in a prototype, three bushings were manufactured with the same inner and outer diameters of the replaced bearings and implemented into the reel, as shown in Figure 16. These were the two handle bushings and the spool bushing mentioned previously and shown in Figure 3.

The bushings were sanded and lightly lubricated with engine oil and inserted in the reel. As the handles are permanently riveted and replacing the bushings involved destroying the current handles, they were left unchanged. However, since their rotation rate and loading is so low, bushings could also replace their ball bearings.

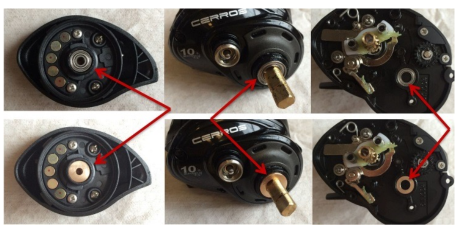

Figure 16 – Pictures of the replaced ball bearings (top) with bushings (bottom).

Two modified Cerros reels were tested to evaluate the effectiveness of the inserted bushings. In order to measure the friction generated by the bushing modifications, these modified reels were compared to several unmodified reels: an Okuma Cerros, an Abu Garcia Orra Inshore, and an Okuma Calera. To test the reels, the drag was turned off and a load cell was attached to the line. The load cell was pulled away from the reel for several seconds and the resulting force recorded. Figure 17 shows a graph of the mean drag force measured in all the reels.

It is clear that the modified Cerros reels with bushings showed a higher drag force than the other reels. However this can be explained by examining the design of the reel. Within the handle, there are three bearings in series, all tightly fit into the housing. The ball bearings in this reel are over-specified for their application and thus will still spin well under misaligned loads. Therefore the handle shaft is over constrained. With bushings, any angular misalignment in the system will generate large normal forces on the shaft and increase frictional torque. A way to counteract this is to leave two bushings floating or with some play in their tolerances, thus allowing the shaft to spin freely when unloaded. This misalignment and its correction are depicted in Figure 18.

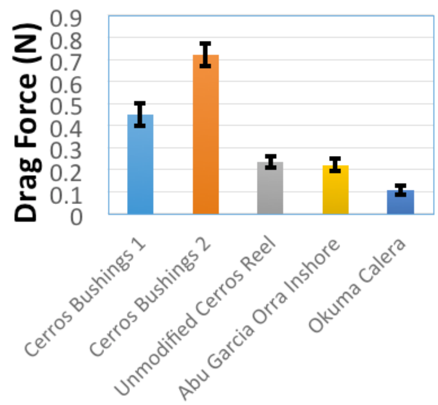

Figure 17 – Drag force in modified and unmodified reels

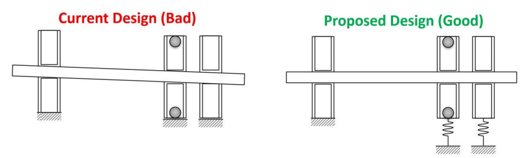

Figure 18 – In the current design, the one-way bearing is surrounded by two supporting bearings, which, when they are changed to bushings, result in unwanted friction if the shaft is misaligned. In the proposed design, two bearings are mounted with compliance such that when the supporting bearings are swapped for bushings, small misalignments do not increase frictional forces.

Since these reels are designed for ball bearings, it makes sense that a modified reel will show increased frictional resistance. Also, the shafts that the bushings housed were left de-burred and were not designed for use with bushings. With proper lubrication, tolerances, and polishing of the bushings and reel parts, this frictional resistance will decrease.

To further understand how the bushings performed, usability testing was done with thirty different people, most of whom were fishing novices. During the test, an unmodified and a modified Cerros reel on identical rods were presented to the users. Subjects were allowed to cast and reel in as many times as they wanted. They were then asked to answer a survey containing three questions. Two extraneous questions were included in an attempt to remove bias from the results. The target question asked about the smoothness of each reel on a scale of one to five. Figure 19 shows the results of the usability testing of thirty subjects, which suggest that users were generally unable to notice a difference in smoothness between the two reels.

As mentioned in Section 4.2, it was determined that the current reel has the optimal magnet orientation, but too many magnetic distance options. Therefore, the modified magnetic braking component contains only three distance options that correspond to the original reel's settings of zero, five, and ten. To determine the efficacy of the system, the modified reel was attached to a dowel in the same manner as in previously

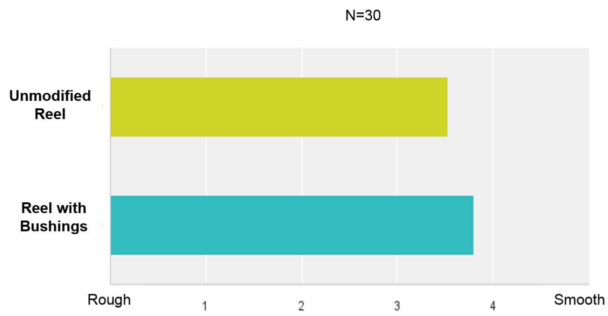

Figure 19 – Results of usability testing

performed magnet tests. Tests were performed with the friction cast control completely disengaged. Figure 20 shows the comparison between the modified and current magnetic breaking system designs.

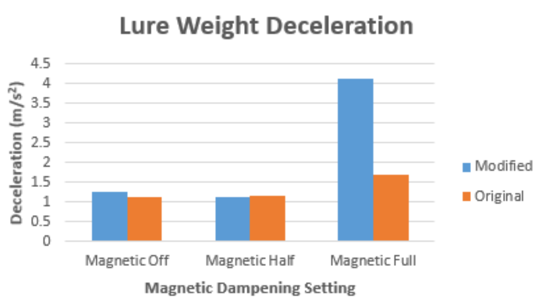

Figure 20 – Modified reel deceleration test

From these data, it is apparent that the modified system achieves braking power comparable to that of the current reel when the magnets are farthest away and on the middle step (original reel setting of five). When they are fully engaged (original reel setting of ten), the modified design is more effective at decelerating the spool. This difference suggests that the magnets were slightly too close on the maximum setting in the prototype, and should be slightly further from the spool in future prototypes. Figure 21 depicts the braking forces observed when using a simplified system. Note that the usability could be improved with intuitive naming of each setting.

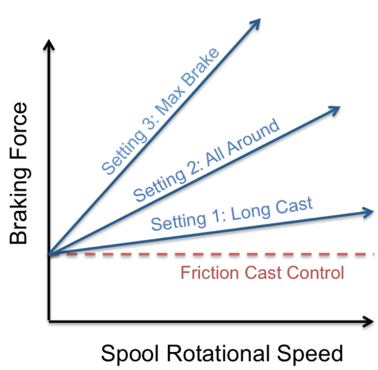

Figure 21 – Simplified reel settings

6. CONCLUSION AND NEXT STEPS

The purpose of this project was to modify the Okuma Cerros to produce a baitcasting reel that is both less expensive and more user-friendly than those currently on the market, such that a beginning fisherman will choose to buy both a spinning and a baitcasting reel. We have achieved both our goal of cost reduction and of improved user-friendliness, but there remain several tasks to complete before the final product can be released to market. In the cost reduction phase, further investigation into lubricated bronze bushings and plastic gears is required. Though preliminary analysis and experiments have suggested that bronze bushings and plastic gears would be suitable replacements for their counterparts in the current reel, validation of this hypothesis requires building a production-grade reel with all parts switched out and ensuring it meets all design requirements. For the magnetic braking prototype, additional tests need to be performed to determine the optimal placement of the three magnet levels that best replicate the magnetic braking system on the current reel. Additionally, as the user interface design changes are thus far only conceptual, the next step requires fabricating a full-scale prototype and running it through user tests and design iterations until an optimal user interface design is achieved. The team is confident that by working through these steps with Okuma, it will be able to create an improved Cerros reel that appeals to beginning fisherman in Brazil as well as around the world.

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