To the Graduate Council:

I am submitting herewith a thesis written by Nathan Baker entitled "Process Improvement of Segmented Cage Bearing Assembly." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Masters of Science, with a major in Mechanical Engineering.

Frank Speckhart, Major Professor

We have read this thesis
And recommend its acceptance:

Accepted for the Council:

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Process Improvement of Segmented Cage Bearing Assembly

A Thesis
Presented for the
Masters of Science
Degree
The University of Tennessee

Nathan Baker
May 2001

Abstract

This is a study to reduce the cost and time involved in the assembly of cylindrical roller bearings with an X-style retainer. The data of X-style bearing assembly techniques was collected at Link-Belt Bearings in Clinton, Tennessee, during normal business operations. The current assembly process was recorded and then studied to find ways in which improvements could be implemented. The baseline information showed that it took four operators to perform four separate operations to completely assemble one bearing. All existing tooling for the four operations was studied closely and then redesigned. A redesign of the tooling proved that the same bearing could be completely assembled in two operations with two operators at a time savings of about 25%. Further investigation theorized that by automating the process one operator could build a full bearing in 50% of the time of the current four operation standard. There was a change in business conditions making the payback on an automated machine unattractive and the machine design was ended at a design concept. The project was ended with a method of reducing operator labor by 50% and time to build a bearing reduced by 25%.

Table of Contents

1. BACKGROUND **1**

GENERAL LINK-BELT 1
GENERAL CYLINDRICAL BEARINGS 1
GENERAL X-STYLE BEARINGS AND ASSEMBLY 3
THESIS GOALS 7

2. BASELINE INFORMATION **9**

CURRENT PROCESS 9
PHASE 1 - OPPORTUNITIES TO EXPLOIT – FIXTURE DESIGN 12
PROBLEM – OPERATION 1 13
SOLUTION – OPERATION 1 14
SOLUTION – OPERATION 3 15
OPPORTUNITIES TO EXPLOIT – PHASE 2 MACHINE DESIGN 16

3. LOW COST/LOW RISK IMPLEMENTATION **17**

COMBINATION OPERATION 1 18
COMBINATION OPERATION 1 FIXTURE DESIGN 17
COMBINATION OPERATION 1 FIXTURE RESULTS 18
COMBINATION OPERATION 3 20
COMPARISON OF NEW VS. OLD 23

4. HIGH COST/HIGH RISK IMPLEMENTATION **26**

MACHINE CRITERIA 26
FINANCIAL CONSIDERATIONS 28
BASIC CONCEPT 29
BASIC OPERATION 33
OPERATION NOTES – ASSEMBLY CX-16000-101 – ROLLER LOADER 34
OPERATION NOTES – ASSEMBLY CX-16000-102 – SEGMENT LOADER 37
OPERATION NOTES – ASSEMBLY CX-16000-103 – BUILD FIXTURE 38
OPERATION NOTES – ASSEMBLY CX-16000-104 – MACHINE BASE AND BUILD FIXTURE ROTATION MECHANISM 39
OPERATION NOTES – ASSEMBLY CX-16000-105 – END RING RAM AND LINEAR SLIDE 39
OPERATION NOTES – ASSEMBLY CX-16000-106 – END RING RAM FIXTURE 40
OPERATION NOTES – ASSEMBLY CX-16000-107 – SEGMENT AND ROLLER LOADER LINEAR ACTUATOR 41
OPERATION NOTES – ASSEMBLY CX-16001-101 – BEARING PRESS TOP FIXTURE 42
OPERATION NOTES – ASSEMBLY CX-16001-102 – BEARING PRESS BOTTOM FIXTURE 42
OPERATION NOTES – ASSEMBLY CX-16001-103 – HYDRAULIC PRESS 43
RISKS 43

5. DESIGN FOR OPERATOR **46**

BASELINE INFORMATION 46
PROPOSED CHANGES 47

6. CONCLUSION **49**

SUMMARY 49

REFERENCES **54**

APPENDIX LISTINGS **56**

APPENDIX 1 – BASELINE DATA 57
APPENDIX 2 – COST PER OPERATION 58
APPENDIX 3 – COST OF MACHINE FABRICATION 59
APPENDIX 4 – END RING LOADER CONCEPT 60
APPENDIX 5 – CX-16000-101 – ROLLER LOADER 61
APPENDIX 6 – CX-16000-102 – SEGMENT LOADER 62
APPENDIX 7 – CX-16000-103 – BUILD FIXTURE 63
APPENDIX 8 – CX-16000-104 – MACHINE BASE AND BUILD FIXTURE ROTATION MECHANISM 64
APPENDIX 9 – CX-16000-105 – END RING RAM AND LINEAR SLIDE 65
APPENDIX 10 – CX-16000-106 – END RING RAM FIXTURE 66
APPENDIX 11 – CX-16000-107 – SEGMENT AND ROLLER LOADER LINEAR ACTUATOR 67
APPENDIX 12 – CX-16000-201 – ROLLER AND SEGMENT INSERTION MACHINE 68
APPENDIX 13 – CX-16001-101 – BEARING PRESS TOP FIXTURE 69
APPENDIX 14 – CX-16001-102 – BEARING PRESS BOTTOM FIXTURE 70
APPENDIX 15 – CX-16001-103 – HYDRAULIC PRESS 71
APPENDIX 16 – CX-16001-201 – BEARING PRESS MACHINE 72
APPENDIX 17 – CX-16000-301 – MACHINE ASSEMBLY 73

VITA **74**

List of Tables

TABLE 1 – AVERAGE BUILD TIME OF A SET OF TEN BEARINGS BY OPERATION 10
TABLE 2 - OPERATION 1 PROCESS STEPS FOR MANUALLY BUILDING AN OPERATION 1 ASSEMBLY 10
TABLE 3 - OPERATION 2 PROCESS STEPS FOR MANUALLY BUILDING AN OPERATION 2 ASSEMBLY 11
TABLE 4 - OPERATION 3 PROCESS STEPS FOR MANUALLY BUILDING AN OPERATION 3 ASSEMBLY 11
TABLE 5 - OPERATION 4 PROCESS STEPS FOR MANUALLY BUILDING A COMPLETED BEARING (OPERATION 4 ASSEMBLY) 12
TABLE 6 – COMBINATION OPERATION 1 PROCESS STEPS FOR MANUALLY BUILDING A COMBINATION OPERATION 1 ASSEMBLY 17
TABLE 7 – TEST RESULTS OF SEPARATE OPERATION 1 AND 2 AND COMBINATION OPERATION 1 FIXTURES 19
TABLE 8 – PROCESS STEPS TO BUILD OPERATION 3 AND 4 USING THE CURRENT AND COMBINATION FIXTURES 23
TABLE 9 – COMPARISONS OF CURRENT FIXTURES VS. COMBINATION FIXTURES TO BUILD MU1308X WITH A YEARLY PRODUCTION QUANTITY OF 3000 BEARINGS. 24
TABLE 10 – ESTIMATE OF MACHINE COMPONENTS AND PRICE 29
TABLE 11 – OPERATION OF MACHINE BY THE STEPS OF EACH BUILD OPERATION 31
TABLE 12 – MACHINE ASSEMBLY NUMBER AND FUNCTION 34
TABLE 13 – THE APPARENT CHANGE IN COST AND PRODUCTION BY BUILD FIXTURE TYPE 50

List of Figures

FIGURE 1 - EXAMPLES OF POLYMERIC, FORMED STEEL, X-STYLE, AND BRONZE CAGES 3
FIGURE 2 - FULLY ASSEMBLED DOUBLE RIBBED INNER AND OUTER RING X-STYLE BEARINGS 4
FIGURE 3 - OPERATION 1: COMPLETED OPERATION 1 ASSEMBLY 4
FIGURE 4 - OPERATION 1: OPERATOR LOADING SEGMENTS BY HAND 4
FIGURE 5 - OPERATION 2: COMPLETED OPERATION 2 ASSEMBLY 5
FIGURE 6 - OPERATION 2: OPERATOR INSERTING OPERATION 1 ASSEMBLY 5
FIGURE 7 - OPERATION 3: COMPLETED OPERATION 3 ASSEMBLY 6
FIGURE 8 - OPERATION 3: OPERATION 2 ASSEMBLY IN FIXTURE 6
FIGURE 9 - COMPLETED BEARINGS 7
FIGURE 10 - CURRENT OPERATION 1 MANUAL ASSEMBLY FIXTURE 13
FIGURE 11 - CURRENT OPERATION 3 MANUAL ASSEMBLY FIXTURE 15
FIGURE 12 - CURRENT OPERATION 4 MANUAL ASSEMBLY FIXTURE 15
FIGURE 13 - COMBINATION OPERATION 1 FIXTURE FOR MANUALLY BUILDING A COMBINATION 1 OPERATION ASSEMBLY 18
FIGURE 14 - COMBINATION OPERATION 3 FIXTURE - STATIC 21
FIGURE 15 - COMBINATION OPERATION 3 FIXTURE - DYNAMIC 22

1. Background

General Link-Belt

Link-Belt Bearings in Clinton, Tennessee, is a producer of metric cylindrical roller bearings. A roller bearing is an anti-friction device used between two rotating parts that are operating under high loads, low speeds, minimal misalignment, and minimal thrust load. Link-Belt Clinton started operation in 1974 and employs approximately 275 people on three shifts. Production at Link-Belt starts with raw tube stock and ends with complete bearings. Operations at Link-Belt include turning, cold forming, heat-treating, grinding, and assembly. The majority of Link-Belt production is for original equipment manufacturers. Applications for Link-Belt products include transmissions and axles, pumps, construction equipment, and farming equipment. The production quantity varies for each bearing size and configuration. Yearly, Link-Belt ships a total of about three million bearings.

Bearing bore sizes produced at the Clinton facility range from 25mm up to 280mm.

General Cylindrical Bearings

A cylindrical bearing is similar in appearence to a ball bearing. Both types of bearing have circular inner and outer rings that are stationary relative to the surface they are pressed against while the balls or rollers in between the rings rotate. Ball bearings have

point contact between the bearing races and the balls and are used in high-speed applications with low load. Cylindrical bearings have rollers that create line contact between the bearing races and rollers. Line contact distributes the load across the face of the roller allowing roller bearings to handle greater loads than ball bearings. Conversely, line contact creates more friction and heat requiring that roller bearings be used in lower speed applications than ball bearings. Neither ball nor roller bearings are suitable for applications that have more than minimal thrust or misalignment.

Common components in roller bearings are rollers, inner ring, outer ring, and roller cage. The configurations of bearings vary from all of the components; to rings and rollers, ring, rollers, and cage, to just a cage and roller assembly. Inner rings can have between zero and two ribs. The rib configuration is dependent upon the end application and takes into account assembly and thrust loads. Outer rings also come with between zero and two ribs depending on the application. Rollers are all cylindrical with a slight radius on each end edge. The ends are ground parallel and can be flat or dimpled depending on the manufacturing technique. Cages come in four styles: formed steel, bronze, polymeric, and X-style shown in Figure 1. Formed steel cages are used when bearing speed is a consideration. The bronze cages have low heat generation and noise generation characteristics. Polymeric cages are made of a nylon material that have the same advantages as bronze, but are cheaper. A limitation on polymeric cages is that they have to operate in lower temperature environments than bronze. X-style cages are made from steel segments and two steel end rings that are press fitted onto the ends of the segments. The X-style cage represents a trade between speed and load capacity. A

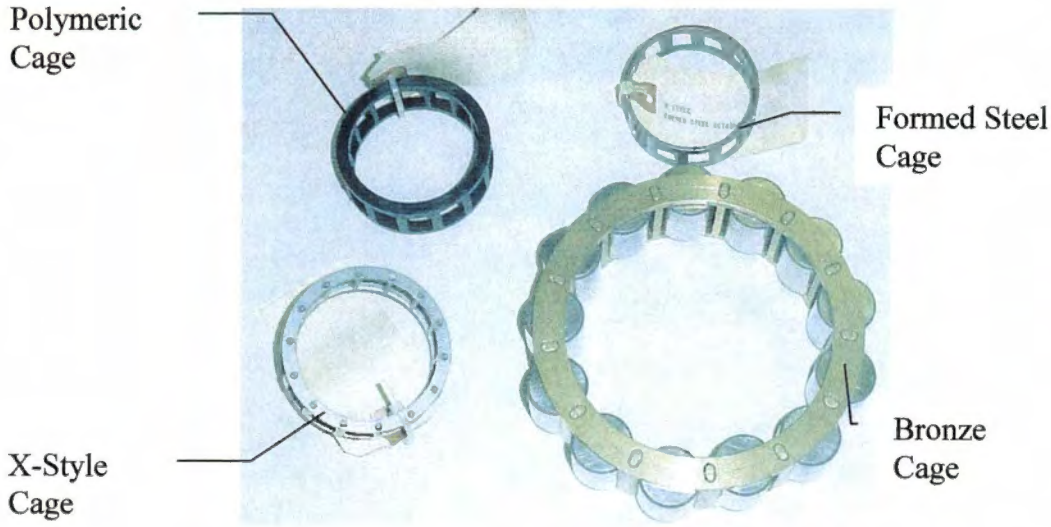


Figure 1 - Examples of Polymeric, Formed Steel, X-style, and Bronze Cages

bearing with an X-style cage can handle higher speed and generally more load than a formed steel cage, but are more expensive to manufacture. Bearings that have that have no cage handle the highest load, but run at the lowest speed.

The cages are critical to keep the rollers parallel to each other. When a cage skews, wears, or disassembles this leads to the rollers skewing and rubbing against the ribs or other rollers causing premature bearing failure.

General X-Style Bearings and Assembly

The segmented X-style cage is composed of two end rings and one segment for each roller. A segmented X-style bearing most often has the following components: inner ring, outer ring, rollers, and X-style cage shown in Figure 2.

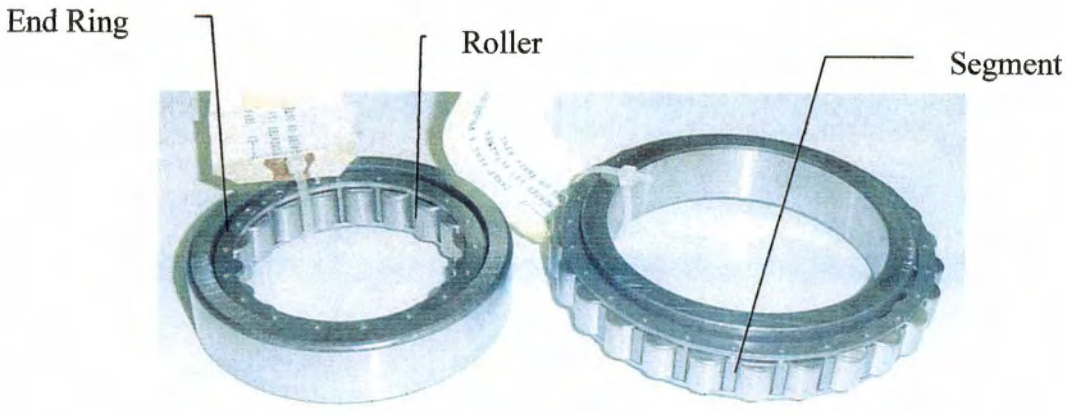


Figure 2 - Fully Assembled Double Ribbed Inner and Outer Ring X-Style Bearings

The assembly process for an X-style bearing is broken down into four individual operations:

1) Operation 1

   A) The operator inserts the segments into a fixture as shown in Figure 4.

   B) An end ring is placed on top segments in the fixture.

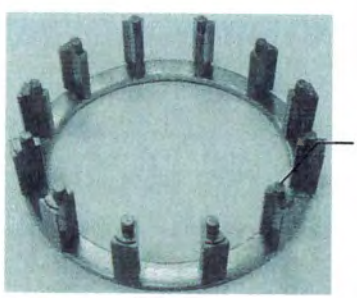


Figure 3 - Operation 1: Completed Operation 1 Assembly



Figure 4 - Operation 1: Operator Loading Segments by Hand

C) The end ring and segments are put in a press and assembled by a press fit between the segments and the end ring.

D) The completed Operation 1 assembly (Figure 3) is removed from the fixture and sent to the next build station.

1) Operation 2

A) The operator places the bearing ring on a fixture.

B) The operator hand inserts the rollers into the fixture.

C) The operation 1 assembly is placed in the fixture with the segments between the rollers as shown in figure 6.

D) The completed operation 2 assembly (Figure 5) is removed from the fixture and sent to the next build station.

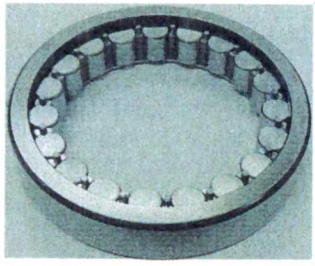


Figure 5 - Operation 2: Completed Operation 2 Assembly

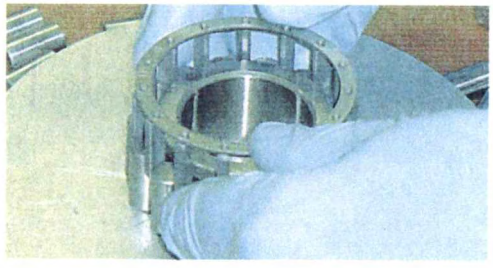


Figure 6 - Operation 2: Operator Inserting Operation 1 Assembly

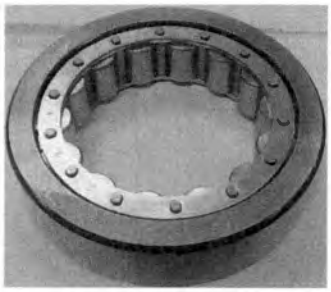


Figure 7 - Operation 3: Completed Operation 3 Assembly

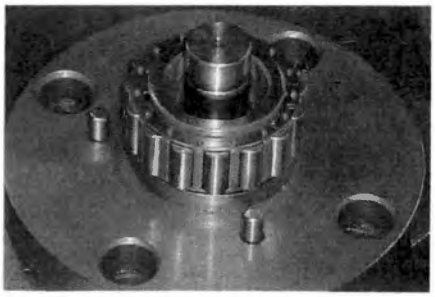


Figure 8 - Operation 3: Operation 2 Assembly in Fixture

2) Operation 3

A) The operation 2 assembly is placed in a build fixture.

B) The second end ring is placed on the segments of the assembly in the fixture as shown in Figure 8.

C) The fixture is placed in a press and the end ring is attached to the 2nd operation assembly by a press fit.

D) The completed operation 3 assembly (Figure 7) is removed from the fixture and sent to the next operation.

3) Operation 4

A) The operation 3 assembly is placed in a fixture.

B) The fixture is put in a press where an identification groove is put in the segments

C) The completed bearing (Figure 9) is ready for shipping to a customer.

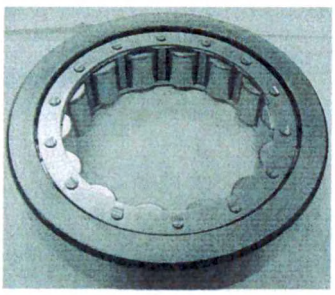


Figure 9 - Completed Bearings

Thesis Goals

A review of the assembly method for the highest production volume X-style bearings is proposed. The proposal is to reduce assembly time, lowering cost, easing operator labor, and reducing wasted labor for the highest production bearing. The project will entail three phases.

1) Phase 1 - Identification and suggestions for problems and opportunities - The opportunities that arise be will evaluated on three criteria: cost, risk, and benefit.
2) Phase 2 - Implementation of low cost, low risk opportunities – The opportunities that are low risk, low cost, and high benefit. Low cost opportunities will probably be simple things like new tooling or a change in work area layout.
3) Phase 3 - Implementation of higher cost, higher risk opportunities – The opportunities that are high benefit, but high risk or cost. An opportunity that is high cost is a new machine.

The implementation of solutions will be limited by restrictions imposed by the management of Link-Belt bearings who have to consider budget, manpower, and labor issues.

The techniques for identifying problems include:

1) First hand production analysis
2) Audits of production and cost records
3) Interviews with operators and personnel

Establishment of a baseline of the current process may offer suggestions to change labor practices, purchase new equipment, or redesign an area or operation. Any suggestions from the baseline will include estimates of the cost and anticipated benefits of any changes. Phase 3 implementation depends heavily on management approval of project and capital. The implementations of Phase 3 may include fabrication of new machines or tooling, rearrangement of existing equipment, or changes in operator work instructions. All new equipment built or purchased will show a payback within twenty-four months at Link-Belt's 15% internal rate of return. The current capital budget for this project is $20,000 for Phase 2. The capital budget for Phase 3 is dependent on market conditions.

The entire project has an element of risk due to being a privately financed project for a profit driven company. A danger exists that the market will turn and funding for this thesis will be cancelled. There is a low risk of cancellation of Phases 1 and 2 due to the low capital expenditures level. The risk of not completing Phase 3 is high due to the potential sensitivity to capital spending by the company.

2. Baseline Information

Current Process

The first step to reducing waste is to find what the current time and steps are in the process. The MU1308X and M1308EX bearings were chosen as the test subjects for two reasons: the high built quantity, and the bearing size and weight is an average size. Differences between the MU1308X and M1308EX are that the former bearing is a double ribbed inner ring and latter is a double ribbed outer ring. As explained in the introduction there are four operations required to assemble an X-style cage.

The test procedure to find the build time for each operation was performed as follows. Time was measured to hand build operations 1 through 4 as described in the introduction. An operator built up a set of ten bearings or assemblies, and the time to build the entire set of ten was recorded. Getting a time for ten complete built bearings at each operation balanced out the variation in the cycle times of individual bearings. Each operation was recorded for time over seven to twelve of the ten bearing sets. The limiting factor was the amount of product to be shipped. The time trials ended when the daily quotient of bearings had been built.

The average times required to build ten pieces is summarized in the table below. The complete data can be found in the Appendix 1.

Table 1 – Average Build Time of a Set of Ten Bearings by Operation

	Operation 1	Operation 2	Operation 3	Operation 4
Time (s)	292	254	82	87

Operations 1 and 2 take three times longer to perform than operations 3 and 4. Operations 1 and 2 are much more labor intensive than operation 3 and 4 as can be seen from the process steps in Table 2.

Most of the time to build in operation 1 is the insertion of segments in step one. The motion of grabbing a segment, picking it up, lifting it over to the fixture, lining it up in the hole, fitting it in place, then repeating for the remaining ten segments takes the most time in the process. The other steps are less time consuming due to only being performed once. Fitting the segments into the fixture can be time consuming from the tight fit, and the jamming that can occur.

Table 3 shows the steps of operation 2. In operation 2 the most time is consumed at step 2. The majority of the time is spent at step 2 because it requires the repeated placement of several rollers similar to step 1 of operation 1. Step 2 of operation 2 is

Table 2 - Operation 1 Process Steps for Manually Building an Operation 1 Assembly

Step	Build Process
1	Insert segments in Fixture
2	Insert end ring in Fixture
3	Place top onto Fixture
4	Put Fixture in press
5	Press fixture
6	Remove fixture from press
7	Remove top of fixture
8	Remove assembly from fixture
9	Put assembly in basket

Table 3 - Operation 2 Process Steps for Manually Building an Operation 2 Assembly

Step	Build Process
1	Insert ring into fixture
2	Insert rollers into fixture
3	Insert assembly into fixture
4	Remove bearing from fixture
5	Stack bearings in basket

quicker due to the looser fits and low occurrence of jams. Total number of steps is also lower than operation 1, allowing for a quicker build process.

Operation 3 in Table 4 and operation 4 in Table 5 are very similar and are worth discussing together. Unlike operations 1 and 2 there are no repeated actions like the insertion of the segments or rollers. The differences between operation 3 and 4 is that operation 3 requires an end ring be inserted and operation 4 has a manual spin test step. Manual spin testing takes slightly longer than placing an end ring, which causes the discrepancies in the times.

Table 4 - Operation 3 Process Steps for Manually Building an Operation 3 Assembly

Step	Build Process
1	Put assembly in fixture
2	Insert end ring onto bearing
3	Place top on fixture
4	Place fixture in press
5	Press fixture
6	Remove fixture from press
7	Remove top of fixture
8	Remove bearing from fixture
9	Place bearing in 4th op staging

Table 5 - Operation 4 Process Steps for Manually Building a Completed Bearing (Operation 4 Assembly)

Step	Build Process
1	Put bearing in fixture
2	Put top on fixture
3	Place Fixture in press
4	Press fixture
5	Remove fixture
6	Remove top of fixture
7	Remove bearing from fixture
8	Manually spin test bearing
9	Stack bearing in basket

The base line for the assembly operation of ten bearings is summarized below-

- Total operations – 4
- Total operation steps – 32
- Total average build time - 715 seconds

Phase 1 - Opportunities to Exploit – Fixture Design

The largest build times are in the first and second operation so that is the first place operation reduction efforts should be concentrated. The most time consuming steps of operations 1 and 2 are also the steps that the customer pays for, and cannot be removed. The time and cost savings can be realized by simplifying the insertion of segment and end rings, eliminating much of the stacking in baskets, and eliminating movement of assemblies.

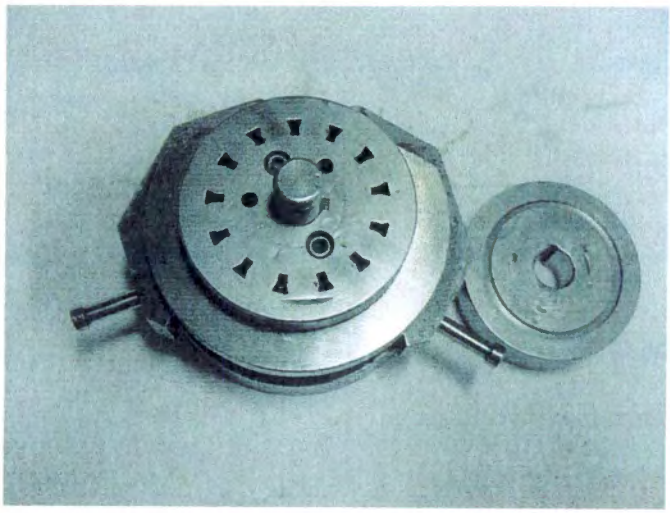


Figure 10 - Current Operation 1 Manual Assembly Fixture

Problem – Operation 1

To reduce the time spent inserting rollers and segments the operation 1 tooling shown in Figure 10 must be scrutinized. Operation 1 fixtures are potentially over designed and excessively difficult to use. The fixture is designed with the fit between the fixture pins and segments tighter than the segment and roller fit to prevent the segments from expanding at the base or developing torsional skew as the end ring is pressed into place. Tight tolerances of the pin make aligning and inserting the segment sometimes difficult. Any difficulty of lining up the segment and inserting it between the pins adds time to the hand assembly, lowers production, and increases total bearing cost. The tight tolerances at production of the fixture also increase cost of the bearing.

Solution – Operation 1

A review of the design and assembly process leads to the conclusion that the operation 1 fixture is over designed. Slots in the fixture act as simulated rollers so it is possible to use real rollers and simplify the assembly fixture. The press operation of the end plate is not as high pressure as the operation 3 and 4 where segment skew often occurs. Elimination of the slots in the fixture does simplify manufacturing and allows the fixture to be produced in-house reducing the cost even further. The design substitution of the rollers for slots in parts with a moderate amount of segments (18 or less) allows a quicker assembly with no additional increase in scrap due to segment skew. Using rollers instead of pins creates a combination operation 1 and 2 fixture. Building operations 1 and 2 in the same fixture removes some of the stacking of assemblies in baskets and moving the assemblies between fixtures. The final advantage to combining the two fixtures is the reduction of inventory. Storage of assemblies between operation 1 and 2 is eliminated causing less money to be tied up in inventory.

Problem – Operation 3

The time required to perform operations 3 and 4 is less than operations 1 and 2, however there are wasted and repeated motions that could be eliminated by combining the two operations. Most of the repeated motion is placing and removing assemblies from

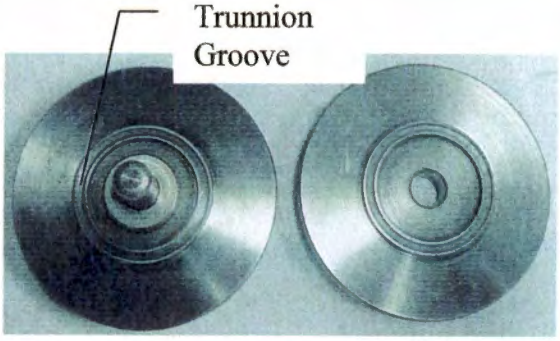


Figure 11 - Current Operation 3 Manual Assembly Fixture

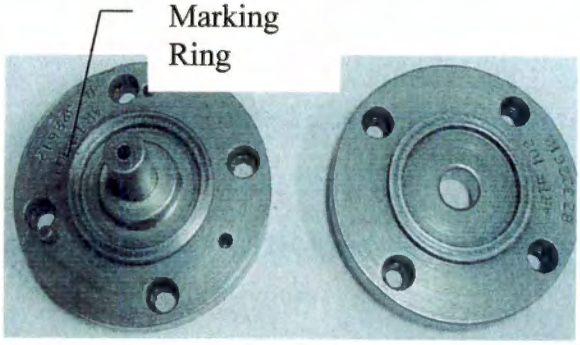


Figure 12 - Current Operation 4 Manual Assembly Fixture

fixtures. Using a combination fixture that performs operations 3 and 4 simultaneously will halve the steps and reduce that time from the baseline. Operation 3 fixture (Figure 11) pushes the end ring over the trunnions causing a press fit to develop between the parts. Operation 4 fixture (Figure 12) adds a groove into the pressed trunnions and flattens the trunnions over the end plate like a mushroom. The test for trunnion seating is a linear pull test. It is believed that most of the cage strength (resistance to being pulled apart) comes from the press fit in the operation 3 with a small amount being added by the flattening of the trunnion in operation 4.

Solution – Operation 3

Operation 4 pressing does not completely flatten the trunnion and part of it is still left above the end ring height. An opportunity to combine operation 3 and 4 lies in the trunnion not being entirely flattened. As long as the end ring is pressed slightly ahead of the marking it should be possible to incorporate both operations into one. The fixture will

look like the current operation 3 fixture with the operation 4 marking groove built inside the trunnion groove. When pressed together the trunnion ends protrudes 0.04 inches above the end ring. The marking ring is staggered 0.02 inches inside the trunnion groove to allow the end ring to be partially pressed on before the marking begins. The last 0.02 inches of travel will simultaneously press the end ring on and put the marking groove in the trunnion.

Opportunities to Exploit – Phase 2 Machine Design

The largest amount of time is the insertion of segments and rollers in operation 1 and 2. To reduce the cycle time this process needs to be automated to drop segments and rollers nearly simultaneously. There is a benefit to automating the press operations and fixture alignments. Creation of a system to perform the operations1/2 and operations 3/4 simultaneously so that one operator could build a bearing would reduce lead-time and inventory. There is a significant cost to creating a machine to perform all of these tasks along with significant benefits. The success of the machine depends on the ability to combine the operation 1 and 2 and the operations 3 and 4. The combination of the operation 1 and 2 along with operations 3 and 4 will allow a machine design with two stations that can be operated by one person at a reasonable expense.

3. Low Cost/Low Risk Implementation

Combination Operation 1

The process map for the combination operation 1 fixture is found in Table 6. The process steps have been reduced from fourteen to ten by the elimination of placing and removing the assembly from two fixtures.

Combination Operation 1 Fixture Design

A test combination fixture was designed based on the second operation assembly fixture in Figure 13. Rollers were used to hold the segments in place instead of slots. The rollers were held in place by the outer ring, the build fixture, and a star fixture to hold the rollers against the outer ring. An end ring was placed on the segments and pressed in place. The entire assembly was then removed from the build fixture. The combination fixture removed a need for the second operation fixture because the rollers were already

Table 6 – Combination Operation 1 Process Steps for Manually Building a Combination Operation 1 Assembly

Step	Build Process
1	Insert rollers into fixture
2	Insert segments in Fixture
3	Insert end ring in Fixture
4	Place top onto Fixture
5	Put Fixture in press
6	Press fixture
7	Remove fixture from press
8	Remove top of fixture
9	Remove bearing from fixture
10	Stack bearings in basket

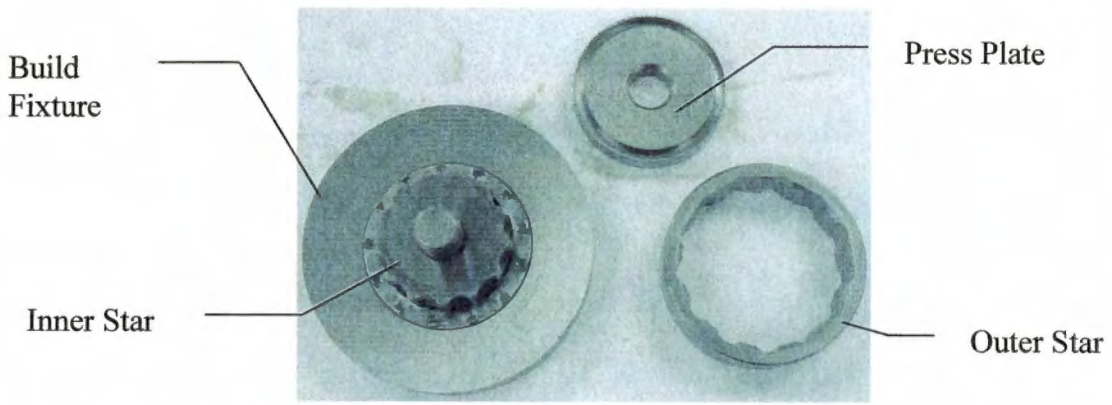


Figure 13 - Combination Operation 1 Fixture for Manually Building a Combination 1 Operation Assembly

mounted in the cage assembly. It was found that the second end ring was a little difficult to seat due to the segment spread from the press operation. The fixture was modified to allow the segment trunnions to fit into the fixture, which reduced spreading. The bearing was then built the rest of the way to test for noise or any other irregularities. The first bearing passed as complete.

Combination Operation 1 Fixture Results

A combination operation 1 fixture was designed and tested. The quality of the combination operation 1 bearings for a MU1308X is equal to the quality of the separate operation 1 and 2 fixtures. In testing bearings built up on the combination operation 1 fixture the noise and pull strength is within acceptable levels for bearings. All bearings built on the combination fixture have been accepted for shipment.

Operator opinions were positive towards the new style. The new combination operation 1 fixture is easier to align and place the segments into the fixture for pressing. Size, weight and complexity of the fixture have been reduced significantly. The combination operation 1 fixture is smaller and less heavy making it easier to place in the press. A potential for higher production over an eight-hour shift due to less operator fatigue may be an unexpected benefit of the combination fixture.

The results of Table 7 show that the same operator can build ten bearings in 498 seconds using the combination operation 1 fixture or 547 seconds with the current operation 1 and 2 fixtures. Using three standard deviations of the mean it would take an operator anywhere from 493 to 601 seconds to assemble ten bearings using the current separate operation 1 and 2 fixtures. Again using three standard deviations it takes from 425 to 571 seconds to build ten bearings using the combination operation 1 fixture.

Table 7 – Test Results of Separate Operation 1 and 2 and Combination Operation 1 Fixtures

Trial	Operation 1	Operation 2	Operation 1+2	Combination Op. 1
1	300	260	560.00	532
2	289	245	534.00	490
3	280	277	557.00	490
4	274	255	529.00	550
5	273	241	514.00	496
6	294	253	547.00	490
7	288	248	536.00	480
8	302	259	561.00	500
9	309	253	562.00	495
10	316	256	572.00	503
11				458
Average	292.50	254.70	547.20	498.55
Std. Dev.	14.47	9.88	18.31	24.52

Operation 1 and 2 fixtures building interval over laps with the combination fixture build interval. The results indicate that on average it is quicker to build using the combination operation 1 fixture. However, on any given set of ten bearings it may be just as quick to build using the current separate operation 1 and 2 fixtures.

The results indicate that, on average, a time saving of 49 seconds can be realized on every ten parts built which is a time saving of 9%. The change in the build process now allows for improvements in part handling, storage of part subassemblies, and operator ergonomics.

Combination Operation 3

The function of operation 3 and 4 is to press on the second end ring and mark both end rings to signify the bearing has been fully pressed and ready for shipment. The operation 3 fixture pushes the end ring over the trunnions causing a press fit to develop between the parts. The operation 4 adds a groove into the pressed trunnions and flattens the trunnions over the end plate like a mushroom. The test for trunnion seating is a linear pull test. It is believed that most of the cage strength (resistance to being pulled apart) comes from the press fit in the operation 3 with a small amount being added by the pressing of the trunnion in operation 4.

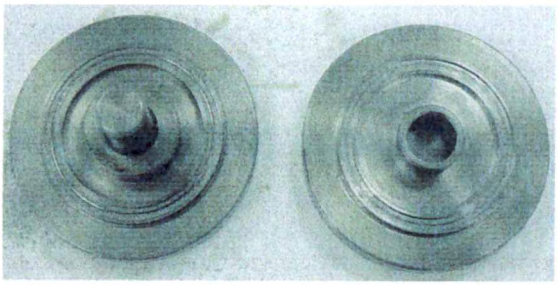


Figure 14 - Combination Operation 3 Fixture - Static

The operation 4 pressing over does not completely flatten the trunnion and part of it is still left above the end ring height. Opportunity to combine operation 3 and 4 (Figure 14) lies in the trunnions not being entirely flattened. As long as the end ring is pressed slightly ahead of the marking operation two operations can be combined into one.

From initial tests the marking groove was not deep enough so the total depth of the groove was reduced to 0.02 with the space between the marking ridge and the lip reduced to 0.01. The tests were performed with the space between marking ridge and lip reduced to 0.01 inch. The test results were initially positive. At press the end ring seated on fully and a groove was visible in the trunnion. The combination fixture did not cause the trunnion to mushroom over the end ring like the separate fixtures. A pull test was initiated to determine if the mushrooming is required to produce the required strength in the cage. Testing the pull strength on the combination cages proved the combination fixture to be a massive failure. The assumption that most of the cage strength comes from the trunnion-cage press fit is not valid. To get the required pull strength the trunnions will have to be mushroomed over the end ring.

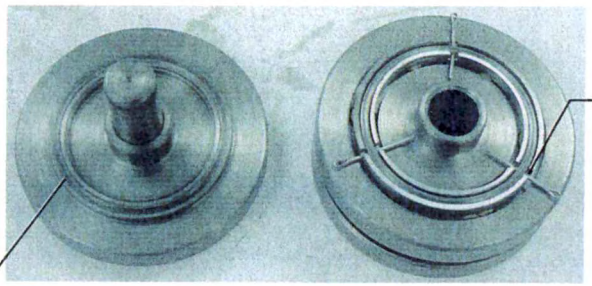


Figure 15 - Combination Operation 3 Fixture - Dynamic

The design of the fixture will have to be altered in order to add the trunnion mushrooming effect. A second test design was to invert the groove so that the trunnion marking is a raised ridge instead of an indented one. The inversion of the groove created a distinct mark and trunnion mushroom, but did not seat the end ring entirely causing a rejected part. An entirely new design is needed that has a dynamic pressing device.

Figure 15 shows the dynamic press fixture with two rings attached to springs to seat the end ring and a static marking ring to mushroom the trunnion. The pressure to seat the end ring is about 300 psi where the pressure to mark the trunnion is about 3000 psi. The press is set to 3000 psi and pushes on the fixture. The springs do not compress below 300 psi and press the end ring over the trunnion up to the segment shoulder. Once the end ring is pressed to the trunnion shoulder the springs will compress and allow the fixed marking ring to mark the trunnion. The bottom of the fixture is a static marking ring because the end ring is pressed and seated in the combination operation 1 fixture.

The dynamic combination operation 3 fixture proved successful in a two bearing initial test. There was a lack of parts available to conduct a full time trial to get reliable build time results. Based on the process steps shown in Table 8 it is a reasonable estimate that the combination fixture has the same time as using only the operation 4 fixture. The

Table 8 – Process Steps to Build Operation 3 and 4 Using the Current and Combination Fixtures

Combination Operation 3 Fixture	Step	Current Operation 3 and 4 Fixture
Put assembly in fixture	1	Put assembly in fixture
Insert end ring onto bearing	2	Insert end ring onto bearing
Place top on fixture	3	Place top on fixture
Place fixture in press	4	Place fixture in press
Press fixture	5	Press fixture
Remove fixture from press	6	Remove fixture from press
Remove top of fixture	7	Remove top of fixture
Remove bearing from fixture	8	Remove bearing from fixture
Manually spin test bearing	9	Place bearing in 4th op staging
Stack bearing in basket	10	Put bearing in fixture
	11	Put top on fixture
	12	Place Fixture in press
	13	Press fixture
	14	Remove fixture
	15	Remove top of fixture
	16	Remove bearing from fixture
	17	Manually spin test bearing
	18	Stack bearing in basket

estimated results are that on average a time saving of 82 seconds can be realized on every ten parts built which is a time saving of 49%. The change in the build process now allows for improvements in part handling, storage of part subassemblies, and operator ergonomics.

Comparison of New Vs. Old

Table 9 gives a summery of the cost and time savings of switching from the current assembly method to the new method devised in this thesis.

Table 9 – Comparisons of Current Fixtures vs. Combination Fixtures to Build MU1308X with a Yearly Production Quantity of 3000 bearings.

Operation	Current 1st & 2nd	Combination 1st/2nd	Current 3rd & 4th	Combination 3rd/4th
Time per Bearing (s)	54.8	49.8	16.8	8.6
% Reduction		**9.14%**		**48.56%**
Cost per Bearing ($)	1.20990	0.92383	0.44164	0.27756
% Reduction		**23.64%**		**37.15%**
Yearly Cost of Production	$3,629.69	$2,771.50	$1,324.91	$832.68
Yearly Cost Savings		**$858.19**		**$492.23**

The results of this study are valid for the building of only one part number at a time. If several parts are built together the savings are much lower. A large portion of the cost savings were realized by the loss of an operator. One operator can build a bearing at combination operation 1 fixture as fast as two operators building one bearing in series. The combination operation 1 fixture does not resolve the bottleneck between operations 2 and 3. Using the separate operation 1 and 2 fixtures and producing in parallel it will take two operators approximately 252 seconds to produce ten bearings. It will take one-operator using a the combination operation 1 fixture 489 seconds to produce ten bearings, or two operators 245 seconds to produce ten bearings. To maintain the production level using the combination fixture will still require two operators. The same is not true of the combination operation 3 fixture. One operator using the combination operation 3 fixture can produce almost as many bearings as two operators using the traditional method.

The real operating conditions are that bearings are built in parallel; under those conditions using the traditional method produces more bearings in the same time period. Cost of more production is more operators, more expensive fixture costs, and higher

inventory and storage costs. The best compromise is to use two combination operation 1 fixtures and two operators. Production rate does not suffer, but there is an added labor cost that is somewhat offset by the much lower fixture and inventory costs.

The use of a combination operation 3 fixture is an economically sound decision. The production rate stays constant with either traditional or combination fixtures, but for the combination fixture the costs are much lower for labor and inventory. The labor to build the combination fixture is slightly more involved. However, it is still possible to build in-house so the cost is already factored into the indirect labor. Indirect labor is the same regardless of which fixture combination is used, or where it is built.

4. High Cost/high Risk Implementation

Machine Criteria

The current redesign of the tooling has managed to reduce the direct labor from four operators to two. Time savings of the combination operation 1 have been minimal so to balance one piece flow it will require two combination operation 1 operators to supply one combination operation 3 operator. The combination of tooling reduces the direct labor by one operator and speeds up production modestly while implementing a one-piece flow. The next step is to automate as much of the process as possible. The machine is a concept with two parts that operate simultaneously and are operated by one person. Combination operation 1 is the first half of the machine and the combination operation 3 is the second half of the machine. Cost of the machine is significantly higher than the tool redesign and the benefits must be significantly higher. The two halves of the machine will retain the one-piece flow like the fixtures, but the number of operators must be reduced and the production rate increased.

To speed up the machine, the assembly of the rollers and segments must be done in parallel instead of series. In a manual operation it is impossible for an operator to install segments and rollers at the same time or in parallel. A machine should be able to install segments and rollers very nearly at the same time, thus reducing the assembly time significantly.

The motion of the operation 3 has been stream lined as much as possible by the combination of tooling. The best hope to reduce labor is to allow the press operation to occur without direct labor.

The change over of tooling on the machine to assemble different bearing sizes and configurations is a major hurdle to over come. The hand assemblies are highly flexible for change over. To switch over a hand build requires an operator walking to a rack, replacing the old tooling, getting the new tooling, returning to work station, adjusting the press pressure, and returning to assembly. The entire change-over takes a maximum of five minutes for a very slow walker. Machine change over is much more complex and will require more planning ahead by the operator to limit change-over to ten minutes or less. The strict rules of SMED will be applied to attain a ten-minute change over. To achieve the change over will require a second setup person that will be charged to indirect labor, which is already accounted for in the indirect labor of the parts. The change over clock starts ticking once the machine ceases producing parts and ends once the first part is again produced. Before the machine is turned off the new tooling will need to gathered and ready to go at the machine. The physical change over of the tooling has been reduced by the avoidance of screws and adjustments. Most of the tooling is held in place by pins and slots.

For the machine to be considered a success it must meet the following operation requirements:

1) Normal operation performed by one person
2) Change over between parts in ten minutes or less.

3) A complete bearing must leave the machine every 25 seconds or less.

Financial Considerations

The total amount spent on all of the medium volume bearings for direct labor, fixed over head and variable over head is just over $145,000 from Appendix 2. A system that simplified all of the assembly operations into one station that could be operated by one person therefore causing a reduction in operations by three would only cause the elimination of the direct labor and variable over head. Fixed overhead from the eliminated operations would be redistributed to the remaining operations, because the fixed overhead costs (electricity, property tax, etc) were not eliminated with the operations. The cost savings realized would actually be more in the range of $100,000 per year. Based on Link-Belt's IRR at 15% over 24 months the total machine cost needs a present value of approximately $170,000 or less.

Total Yearly Savings	$100,000.00
Monthly Savings Yearly/12 Months	$8,333.33
Months of Savings	24
Rate of Return	15.00%
Present Value of Savings	$171,868.62

An initial sketch for design and material ideas was drawn up to give a rough idea of what that machine would look like and what working parts would be required in

Table 10 – Estimate of Machine Components and Price

Part	Quantity	Cost	Total
Bowl feeders	2	$10,000.00	$20,000.00
Cylinders, Couplers, etc	11	$100.00	$1,100.00
Rotary Actuators	2	$1,300.00	$2,600.00
Solenoids, etc	13	$100.00	$1,300.00
Fiber Optic Sensors	8	$100.00	$800.00
Reed Switch, Cords, etc	30	$100.00	$3,000.00
PLC	1	$3,000.00	$3,000.00
Programming (HRS)	80	$30.00	$2,400.00
Part Specific Tooling	10	$5,000.00	$50,000.00
Fabrication Time (HRS)	640	$15.00	$9,600.00
Raw Material	1	$10,000.00	$10,000.00
Total			$103,800.00
Budget			$171,868.62
Budget Remaining (%)			40%

Appendix 3. Table 10 shows an estimate of the materials and building costs. The estimate based off a rough sketch indicates that 60% of the budget is already used. The estimate shows there is 40% of the budget remaining to cover for cost over runs and non-estimated equipment. From the rough estimate and sketches the payback looks good enough to continue with a full design of the project, where a better estimate will be made before construction begins.

Basic Concept

The concept of the machine was to take existing simple repetitive processes that were being performed by hand and automate them. Process of automation was to keep it as simple as possible to keep costs and potential for failure to a minimum. The desire to keep the automation simple required taking a look at the current process and evaluating

each step for any methods to streamline or remove that step all together. Previous chapters detail how the mechanical operations could be stream lined and removed. The machine operation is shown in Table 11. Compromises had to be made in the design between the amount of automation and cost of automation. The decision to have the operator install the end rings by hand was made because it is estimated the cost of automating that step would have put the project over budget. Installation of the snap ring is an interesting design project in itself. The end rings have from between eleven to eighteen holes that have to be aligned with and slid over the segment ends. A sketch of the loader arm concept can be found in Appendix 4. The loader arm is pneumatic fingers attached to a pivot arm on a stepper motor. The fingers grab an end ring from a stack, pivot over the bearing assembly, and lower the end ring onto the segments.

The problem with this design is getting the orientation of the end rings to match the segment orientation. The end rings are shipped in boxes in no orientation or order. To ship rings oriented a specific manor increase cost from the vendor making that an unattractive option. For a person it is not a problem to orient the rings in the state that they arrive, however for a machine it is an entirely separate step and problem. A solution would be to install a feedback to the end rings loader from a vision system. The pivot arm moves the end ring over the segment assembly, the fingers are geared and rotate the end ring, the vision system tells the fingers to stop, and the pivot arm installs the end ring.

Table 11 – Operation of Machine by the Steps of Each Build Operation

Step	Operation 1 of Machine	Operation 2 of Machine
1	**Operator Presses build**	
2	Roller insertion moves forward	Press actuates to press position
3	Table rotates 90 degrees	*Station two presses on end ring*
4	*Rollers fall between teeth as table indexes*	Press returns to home position
5	Segment insertion moves forward	**Operator removes bearing**
6	Table rotates 360 degrees	**Operator places bearing in basket**
7	*Remaining rollers fall into place, as segments fall between positioned rollers.*	**Operator places bearing in basket**
8	Roller insertion moves back	
9	Segment insertion moves back	
10	**Operator inserts end ring**	
11	**Operator Presses Press**	
12	Ram linear actuator slides forward	
13	Ram cylinder actuates to down position	
14	*End Ring is pressed onto bearings*	
15	Ram cylinder returns home	
16	Ram linear actuator slides back	
17	**Operator removes bearing**	
18	**Operator puts on second end ring**	
19	Operator places bearing station two table	

- Normal – Machine Operation
- Bold – Operator Input
- Italics - Bearing Build Operations

The disadvantages of the vision system are an increased cost, increased assembly time, and increased complexity. Cost of the vision system alone is in the $15,000 range. The development of the pivot arm and pneumatic fingers are also in the $15,000 range. Time required for the machine to get an end ring, line it up, and place it on the segments is easily twice as long as it would take a human operator to do the same thing. The addition of the arm and vision system adds a whole new level of complexity and potential for failure. Rotation of the end ring itself is not a simple or easy process for a machine to do. Looking at the entire design the highest risk (most failures) would occur at the end ring loader arm.

An end ring loader arm is not practical from the listed reason, and the draw backs of manual loading are minimal. There will be an operator at the machine whether or not the end ring loader is used. An operator has ample time to load an end ring, and still perform the other tasks required to run the machine.

The second manual task is unloading the cage assembly from the first station, and moving the assembly to the final press operation. This process could be automated more economically than the end ring loader. Steps that need to occur: bearing assembly be removed from the first press fixture, bearing be moved to the second press fixture, bearing seated into the second press fixture, and operator add the second end ring.

Seating the bearing in the second press fixture is simplified because it does not have to be aligned rotationally like the end ring. The largest problem with automation of moving the bearing is the lack of space to get to the bearing. Leaving the current design

of the machine intact a robotic arm with pneumatic fingers is the best design to get in at the bearing, then lift it out, and move it to the next station. Cost to develop the robot is estimated to be greater than $30,000. High cost makes the idea prohibitive, but also the control scheme for the robot would be much more complex than the rest of the controls for the machine. Time required developing the logic and debugging the robot would in itself be a project. Possible methods of failure also increase greatly with the added complexity.

The bearing at the second press will, in either case, have to be handled by the operator due to the end ring. It makes more sense to avoid the complexity and cost of a moving robot and require the operator to move the bearing by hand.

A second alternative to a robot is redesigning the machine to allow more space to get to the bearing to move it. The redesign of the machine is not a good choice because then complexity and cost would then be added to the machine. Current machine design allows part change to be completed in a minimal time. A redesign would not benefit the change over time. To keep the machine simple and economic it is best to manually move the bearings manually between press station one and two.

Basic Operation

The basic operation of each machine part is given in the Table 12. A detailed discussion of each part of the machine assemblies' functions and design intent are given below.

Table 12 – Machine Assembly Number and Function

Assembly Number	Function	Appendix Listing
CX-16000-101	Roller Loader	5
CX-16000-102	Segment Loader	6
CX-16000-103	Build Fixture	7
CX-16000-104	Machine Base and Build Fixture Rotation Mechanism	8
CX-16000-105	End Ring Ram and Linear Slide	9
CX-16000-106	End Ring Ram Fixture	10
CX-16000-107	Segment and Roller Loader Linear Actuator	11
CX-16000-201	Roller & Segment Insertion Machine	12
CX-16001-101	Bearing Press Top Fixture	13
CX-16001-102	Bearing Press Bottom Fixture	14
CX-16001-103	Hydraulic Press	15
CX-16001-201	Bearing Pressing Machine	16
CX-16000-301	Machine Assembly	17

Operation Notes – Assembly CX-16000-101 – Roller Loader

The basic function of assembly CX-16000-101 is to acquire the number of required rollers a bearing requires from the loading device (roller hopper) and to transport the rollers so that they are easily loaded into the bearing. The roller hopper continuously feeds rollers to assembly CX-16000-101 by means of gravity and vibration. The rollers drop into the tube which is the same length as the sum of the lengths of the correct number of rollers. A stationary bottom stop keeps the rollers from dropping out the bottom of the tube. Once the tube has the correct number of rollers no additional rollers will fit in the tube. An actuator from assembly moves CX-16000-107 moves assembly CX-16000-101 into position to load the rollers into assembly CX-16000-103. The stationary bottom stop remains at the load position while the rollers then fall into

assembly CX-16000-103 by means of gravity. The spacing between assembly CX-16000-103 and CX-16000-101 is such that only one roller can fall into each space. If a roller falls between the rotating teeth of assembly CX-16000-103 the roller will stay in position and hold the next roller in the assembly CX-16000-101 tube. As assembly CX-16000-103 rotates the next roller will fall on top of the next tooth. The roller will be held by the tooth on the bottom and kept from rotating by the tube. The assembly CX-16000-103 rotates to the next open slot where the roller falls in place and the process repeats.

This design is based on a similar design used currently in production to assemble a drop center cage type bearing. The benefits of using a tube and gravity to measure roller quantity are the simplicity and cost effectiveness. There are no electronics or sensors to be purchased, programmed or installed reducing cost and decreasing potential for error by simplifying the process. The drawbacks include reliance on gravity and being unable to tell if the quantity of rollers is sufficient.

A real world issue that can occur is if the bowl feeder is not able to keep up with bearing load rate. The potential to build bearings missing rollers is present. A proximity sensor to detect the last roller would be one solution or a hole in the tube so the operator could see if all the rollers were present before starting the cycle. The current system relies on the operator checking the bearing after assembly. One stage of the process involves manual handling, which could also easily involve an operator checking that all rollers are present. There have been no problems of shipping bearings missing rollers in the old system so the added proximity sensor is not a cost justifiable measure.

The linkage of assemblies CX-16000-101 and CX-16000-107 is accomplished by a means of rods and pins. The traditional use of screws has the draw back that it makes change over more difficult and time consuming. The time required to remove a screw, line up the new screw, and then turn the screw back in is significantly longer than simply pulling out and pushing a pin back in. The use of screws also adds the need for tools like screwdrivers and allen wrenches which tend to get lost and misplaced. Searching for a replacement screwdriver wastes precious time from the total change over time. The pusher pin of assembly CX-16000-107 attaches to the back of assembly CX-16000-101 by a pin. Assembly CX-16000-101 has two rods that provide support and guide CX-16000-101 through two bushings in assembly CX-16000-107. The rods have pins in the end to limit the total travel.

The issue with assembly CX-16000-101 and part change over is that every bearing has a difference in rollers and therefore assembly CX-16000-101 will have to be adjusted and/or switched out every time a part change over occurs. It is easier and quicker to remove the entire set of tooling rather than try to adjust. Adjustments tend to take longer because it is very difficult to get it just perfect on the first try and numerous adjustments become required. Using the pins the change over of tooling should be quick and straightforward. The tube design is also impractical for adjustments. Each setup would require a new tube and adjustment to the tube holder which is much more difficult than removing the old holder and installing a new holder. The creation of designated spots for each bearing size and not using a slot type setup can minimize the adjustment of the bowl feeder outlet.

The use of gravity as a roller feeder into assembly CX-16000-103 creates a rough placement of the rollers. Due to the rib of the inner or outer ring it is impossible to drop the roller directly between the teeth of assembly CX-16000-103. A guide was installed at the bottom of assembly CX-16000-107 so that as the fixture rotates the rollers are pushed into place between the teeth against the ring.

Operation Notes – Assembly CX-16000-102 – Segment Loader

Assembly CX-16000-101 is very similar to assembly CX-16000-102 in form and function. Assembly CX-16000-102 is loaded with segments from a bowl feeder. The length of the rods in assembly CX-16000-102 measures the correct number of segments. The shape of the segments makes it more practical to hold the segments in place between two rods instead of inside a tube. For the loading the segments must be oriented to fit between the rollers. A single tube loading system introduces rotation to the segments, which then may not be oriented to fit between the rollers. The segments are narrower than the rollers and do not have to be guided around the ribs of the bearing ring.

The segments fall between the rollers and rest on the assembly CX-16000-103 teeth while supported on the sides by the rollers. The fit between the segments and rollers is loose enough that the segments slide in easily, but tight enough that during pressing skew is not introduced into the cage.

The use of pins and other quick-change tricks used in assembly CX-16000-101 are again used in assembly CX-16000-102. The method of interface with assembly CX-16000-107 and the bowl feeder is the same as explained in assembly CX-16000-101.

Operation Notes – Assembly CX-16000-103 – Build Fixture

The function of assembly CX-16000-103 is to align and hold the rollers and segments in place while the first end ring is pressed on to the segments. Through the use of assemblies CX-16000-101 and CX-16000-102 most of the hand build previously involved has been eliminated. Assembly CX-16000-103 is attached to assembly CX-16000-104 by means of quick-change pins. The stepping motor of assembly CX-16000-104 rotates assembly CX-16000-103 allowing assemblies CX-16000-102 and CX-16000-101 to load the rollers and segments. After the full rotation the operator places an end ring on the assembly. The ram then presses the end ring onto the assembly, which is then removed by the operator and sent to the next station.

Assembly CX-16000-103 is built with teeth that have holes for the segment trunnions. The segments are supported on the segment shoulder by the teeth for two reasons. The first reason is so that during the press the trunnion does not bear the load and deform. The second is to add stability by limiting the available movement of the trunnions during press to avoid skew.

To change to a different part number the three brace pins are removed, the fixture removed, new fixture put in place, and the pins replaced. Different heights of bearings will be compensated for in the CX-16000-101 and CX-16000-102 assemblies.

Operation Notes – Assembly CX-16000-104 – Machine Base and Build Fixture Rotation Mechanism

Assembly CX-16000-104 is the base and drive mechanism for the entire system. Most of the physical size of the machine is in this assembly. The rest of the assemblies mount to assembly CX-16000-104 directly or indirectly. Assembly CX-16000-103 connects to assembly CX-16000-104 to provide the method of rotation for assembly CX-16000-103. A stepper motor in assembly CX-16000-104 provides the power to drive assembly CX-16000-103. The large plate of assembly CX-16000-104 is the base that the other assemblies mount up to.

Operation Notes – Assembly CX-16000-105 – End Ring Ram and Linear Slide

The main purpose of assembly CX-16000-105 is to press the end ring onto the segment and roller subassembly in assembly CX-16000-103. This is made more difficult because placing assembly CX-16000-105 directly over assembly CX-16000-103 will block assemblies CX-16000-101 and CX-16000-102 not allowing any rollers or segments into the build station. To compensate for the blocking issue a linear actuator was built

into assembly CX-16000-105. The build process is that after assemblies CX-16000-101 and CX-16000-102 have returned to their home positions assembly CX-16000-105 actuates to directly over the build fixture, presses the end ring, then returns to the home position.

The linear slide mechanism is two linear bearings and a linear actuator for motion. Linear bearings are built to take the vertical load during the press operation so that the linear actuator does not suffer premature failure. The press operation is about 300 psi to fully seat the end ring onto the segment. Dynamic load capacity of each linear bearing is 600 pounds. Linear bearings are meant to with stand load while sliding, because the load will be applied while the bearing is stationary the bearings should be able to with stand a significantly higher load. Static load of each linear bearing is approximately 1000 pounds. For general design it is estimated the load will be evenly distributed between each bearing giving a factor of safety of 3. Failure mode of the linear bearings will not be catastrophic, but a steady decrease in slide speed and wobble of assembly during press operation. A low factor of safety is warranted considering the slow failure mode, low risk of injury from failure, lack of space for stronger bearing, and the cost savings from the cheaper bearing.

Operation Notes – Assembly CX-16000-106 – End Ring Ram Fixture

Assembly CX-16000-106 is the fixture designed to press the end ring onto the segments. It is attached to assembly CX-16000-105 by means of pins for quick change

over. A fixture plate is designed with channels to allow the end ring to seat with out pushing on the trunnion. This design is adapted directly from the current assembly fixture used in production.

Operation Notes – Assembly CX-16000-107 – Segment and Roller Loader Linear Actuator

This is the portion of the assembly that pushes the roller and segment feeder tracks into the load and home position. It is built using a cylinder with a two-inch stroke to compensate for different size bearings. Because the load position will vary depending on bearing size compensation had to be built into the system. The traditional method would involve screw on tooling and in-process adjustments. By following the SMED methodology tooling is attached by means of pins. To avoid the adjustment of the stroke (by proximity sensors, or other means) a sleeve with a slot was incorporated. The sleeve allows the cylinder to always travel full stroke, but the slot in the sleeve limits the travel of the feeder assembly.

Two bearing and rod assemblies keep the travel of the assembly in the correct orientation and reduce the weight on the cylinder. Pins at the end of the rods again limit the total travel. Bottom brackets are in place to hold the rollers and segments in place during the load operation.

The bearings were chosen to support the load and reduce friction. Because it is a wear surface in linear motion the bearings will have to be periodically replaced. Bearings

were chosen from stock size so that replacement cost and effort is minimized. The push rod rides in a bronze bushing to allow wear to the cheap bushing and reduce friction on the moving push rod. Most wear will occur on the bushing which is a stock size and cheap to replace.

The push rod will see some wear in the slot where it is in contact with the lock pin. A bushing is located inside the push rod to align the pushpin and reduce friction between the pushpin and push rod. Hardening the push rod will minimize the wear at the end of the push rod slots.

Operation Notes – Assembly CX-16001-101 – Bearing Press Top Fixture

Assembly CX-16001-101 is the same as the current hand build fixture with the exception of mounting holes in the base to mount to assembly CX-16001-103. The operation of the assembly CX-16001-201 is very similar to the hand build operation 3 and 4 except it runs without the operator initiating start up and shut down. Assembly CX-16001-101 is a static fixture that presses a marking ring in the trunnions. The fixture CX-16001-101 is mounted by means of quick pins to minimize the change over times.

Operation Notes – Assembly CX-16001-102 – Bearing Press Bottom Fixture

The top of the combination operation 3 fixture is the same as assembly CX-16001-102 with the addition of mounting holes.

Operation Notes – Assembly CX-16001-103 – Hydraulic Press

Assembly CX-16001-103 is a purchased hydraulic press. The press is operated by the PLC of the first machine to eliminate the need for a second operator. When the operator begins the cycle of CX-16000-201 that also starts the press cycle of CX-16001-103 in assembly CX-16001-201. A light curtain is attached to the press that locks out the cycle if the curtain is broken for safety reasons. The press is adjustable to a maximum of 4500 psi.

Risks

The risks to this design include failures due to environment and maintenance equipment. The shop floor environment at Link-Belt is a very fine mist of coolant and oil that dries on all the equipment. When mist dries it becomes slightly tacky to the touch. A danger is that the mist will stick to the roller and segment feed tubes causing the machine to jam at the start of the cycle. There is also a risk the slides will get gummed up and fail to operate properly. This risk is tolerable because machines with similar working functions perform properly.

There is a risk the gravity feed of the rollers and segments will not perform properly or stick. The two options to resolve that issue is either to add an air assist to push the rollers or slow the speed of the build fixture to compensate for slower roller

loading. If the roller and segment feeders are cleaned and maintained properly there should not be a gravity failure.

A possibility exists that due to the fluctuating air pressure assembly CX-16000-105 will not align properly with assembly CX-16000-103 and the end ring will not press on properly. The problem is addressed by three ways. A pressure check valve is introduced at the air inlet of the machine to eliminate the high-pressure spikes. Machine air pressure is set lower than the nominal of the incoming air so a large majority of the time the check valve will keep the machine at a constant pressure. The linear actuator will be installed with proximity sensors so that the press cycle will not initiate until the linear actuator has reached the destination and signaled the programmable logic controller to start the press cycle. The third method is the use of chamfers on the tooling to guide any minor misalignments back to alignment conditions. Chamfers will help minor repeatability issues, but not solve major alignment issues.

The danger of operator injury is always present in any system where moving parts are accessible. To minimize the risk of injury stationary safety guards have been placed everywhere practical. In front of assembly CX-16000-201 it was not practical to place stationary guards because the operator needs access to the area to remove the bearing and place the end ring. To provide safe access a dynamic system of light curtains and Plexiglas shielding was devised. During the roller and segment loading of assembly CX-16000-103 if the light curtain is broken the machine freezes and resumes when the curtain is unbroken. When assembly CX-16000-105 slides over, a shield is attached that slides to cover the opening, blocking access during press operation. If the curtain is

broken as assembly CX-16000-105 is linearly actuating the assembly returns to the home position to avoid pinching an operator as the shield closes. Once the shield is fully closed, if the curtain is broken the press operation automatically cycles back to the home position, and the linear actuator freezes. There is always a risk of injury, but the use of logical guarding tries to minimize the risk.

5. Design for Operator

Baseline Information

The comparison between the current assembly of X-style bearings and a machine assembled operation is radically different from an operator stand point. Current assembly method is almost entirely manual with only the heavy press operation performed by a machine. Operators are responsible for every step of the build process from loading the segments to operating the press. The number of steps in the build process is thirty two, which does not include the indirect labor of keeping raw material at the build stations. There is a misbalance in the process creating overhead from part storage. It takes three times as long for operation 1 compared to operations 3 and 4. The method to balance the lines is that one operator at each operation 3 and 4 are supplied by two operators of operation 2 who are supplied by three build stations of operation 1. Due to the cost of tooling each of the operators at operation 1 are building a separate part number, as are the operators at operation 2. The two operators at operation 3 and 4 are switching back and forth between what is built by the two operation 2 assemblers. When the operation 3 and 4 operators out built the operation 2 operator they build the backlog from the off shift operation 2 where there is no operation 3 and 4 operator. Amongst all of this confusion there is a lot on inventory sitting waiting to be built and switching among short runs. Due to the very quick change over times the short runs are not an issue. Another increase to the bottleneck are the inconsistency of raw material arrival. The raw material for

MU1308 may arrive at operation 1 where it is built. The MU1308 then sits at operation 2 because the raw material has not arrived. The inventory then adds cost to the product, and a headache because the already delicate build balance is even more upset.

The baseline for operator input is that it takes four operators of direct labor to hand build and be involved in every step of the process. The line is not balanced and the raw material flow is inconsistent causing excess inventory. The process to build a bearing involves four separate operators placing and lifting the same bearing into and out of baskets for storage and transport four separate times. Over the course of a full eight hour work shift the amount of lifting and moving bearings becomes tiring.

With the new OSHA regulations on repetitive motion and work related injuries the process of hand building bearings has become a work related safety issue. The method of avoiding repetitive stress injuries has been to rotate operators from job to job over certain time intervals. The best method of avoiding repetitive stress injuries would be to eliminate the repetitive task like placing segments or lifting bearings.

Proposed Changes

The best solution for reducing operator effort is to automate as much of the X-style process as possible. Implementation of the machine design will eliminate the bottleneck between first and second and between second and third. Inherent to the machine is one piece flow eliminating the inventory between the previous operations. The number of operators is reduced to one that is doing a less strenuous job. The role of

the operator for the machine is no longer to build parts manually, but to unload and maintain the operation of the machine. The labor steps of the machine operator are pressing go, placing one end ring, removing the bearing, placing the second end ring, placing the bearing, and removing the bearing. The number of times each bearing is handled is cut from four to two, and the amount of space the bearing travels is reduced from over a hundred feet to less than five.

The risk of repetitive motion is reduced almost entirely. There is still a little danger with the lifting of the bearings and fitting end rings, however it is significantly lower than the danger imposed by placing rollers and segments all day. Headaches of building when not all raw materials are available are gone, because the machine needs all the raw material or build cannot begin. Inventory of half built bearings are eliminated by shifting built inventory to raw material which is cheaper to store.

The second best alternative is to implement the new tooling. The build methodology is the same as the current system so operator labor is much more intensive than an automated process. Introduction of the combination tooling also does not reduce the risk of repetitive motion injuries like the machine. Advantage of the combination tooling is the elimination of inventory between the first and second and the third and forth operations. There also is a reduction in operators moving bearings. The combination tooling does not help the bottleneck between second and third. The cost of a combination operation 1 fixture is much lower than a traditional operation 1 fixture opening the possibility of several combination operation 1 operators on the same part feeding a combination operation 3 operator reducing the inventory and bottlenecks.

6. Conclusion

Summary

The goal behind this thesis project was to take a real production situation, scrutinize the process, evaluate inefficiencies, and create a more efficient process. The quantifiable goals of this project were to increase production, reduce labor, reduce direct cost, reduce operator effort, and lower inventory. The project was broken down into three manageable steps: a baseline and suggestions, implementation of low cost improvements, and implementation of higher cost improvements.

The low cost improvements focused around the redesign of four separate operations conducted by four operators reduced into two separate operations conducted by two operators. Final results in Table 13 indicate that due to the time discrepancies at each operation balancing the build operations, in a cost effective manner, requires at least two operators at the first operation to supply one operator at the final operation. Cost is reduced somewhat, inventory remain the same, and production is reduced. Build time on the current process appears so low because the final operation is building from prebuilt inventory in a batch fashion. Operation 1 and 2 parts are built then stored in inventory, when a customer order appears the stock is pulled from inventory and built up at the operation 3 and 4 giving the appearance of fast cycle time. The cost associated with holding inventory and the loss of production floor space to store inventory is not easily calculated, but management has made the reduction of inventory a priority. It appears

Table 13 – the Apparent Change in Cost and Production by Build Fixture Type

Per Bearing	Current	Combination
Cost	$2.1355	$1.8663
% Reduction		12.61%
Production Rate	87	250
% Reduction		-65.20%

impossible to create a balanced one-piece flow at a reasonable cost using any type of manual fixture build method. Final press is quicker than the other build operations, which makes balancing the line to a one piece flow extremely difficult in a cost effective method.

One of the benefits of one machine dedicated to assembling segmented cages is the reduction of direct labor. A one-piece flow can be achieved on the traditional four-operator set up, however the labor times for one bearing vary from 25 to 9 seconds. Three operators will be idle for 16 seconds while they wait for the bottleneck to be cleared. A bottleneck is still present to some extent on an automated system, but there is only one operator so three operators are not sitting idle 64% of the time. A one-piece flow is realized reducing the amount of inventory.

A machine dedicated to the assembly of segmented bearings eliminates the problems that occur from the fixture building. Operator labor is reduced drastically, and the production rate is increased. One-piece flow is practical and economical. Cost per bearing is cut almost in half. The problem with a machine is that the start up costs are about much greater than the initial costs of a batch fixture build operation.

Several business events have occurred since the original idea was conceived. A segmented assembly automation machine was designed, but will not be built in the near

future. The largest cause has been a down turn in business and a freeze on capital spending. The estimated cost of the machine is approximately $104k. The estimated quantifiable payback in two years is $170k. From the initial numbers the project looks good.

Since the project was approved there has been a down turn in the bearing market. The project has been cancelled due to a freeze on capital expenses and general reduction on expenditures. Current market conditions have caused voluntary temporary layoffs and a general state of uncertainty for the business in general.

One of the risks involved with completing the project is that the payback may never be reached. The return on investment was calculated at a time when 40% more products were being produced. Due to the down turn there has been a slowing of demand. Reducing the savings by 40% lowers the payback to $103k, which does not meet the payback requirements.

The human labor environment is also a concern. Before the market down turn when shipment lagged delivery of customer orders, the work force was open and receptive to process improvements that could free up labor to work on other parts of the back log. In the current climate of uncertainty with potential layoffs or shortened work-weeks the reduction of more jobs will not be welcomed. Although, the best hope is that the machine would be accepted, it is more likely that the machine would not be used due to fictionalized "operational issues" like a created operational failure. There is also a potential for sabotage, while not great, "accidents" have occurred before.

The final results of this thesis will be turned over to Link-Belt management with the following recommendations:

1) Immediate implementation of the Combination operation 3 fixture.
2) Immediate work to balance the assembly part flows to utilize the combination operation 1 fixture and reduce inventory.
3) At return to previous business levels build assembly machine.

References

References

1. Shetty, D., and Kolk, R. A., Mechtronics System Design, PWS Publishing Company, Boston, 1997

Appendix

Appendix Listings

Description	Appendix Listing
Baseline Date	1
Cost per Operation	2
Machine Cost Estimate	3
End Ring Loader Concept	4
CX-16000-101	5
CX-16000-102	6
CX-16000-103	7
CX-16000-104	8
CX-16000-105	9
CX-16000-106	10
CX-16000-107	11
CX-16000-201	12
CX-16001-101	13
CX-16001-102	14
CX-16001-103	15
CX-16001-201	16
CX-16000-301	17

Appendix 1 – Baseline Data

M1308EX Before				
Baseline Test Data				
Time Required to Build at Each Phase				
	1st	2nd	3rd	4th
1	260.00	184.00	81.00	102.00
2	268.00	166.00	77.00	85.00
3	244.00	158.00	82.00	86.00
4	246.00	162.00	82.00	82.00
5	250.00	150.00	84.00	87.00
6	275.00	173.00	89.00	82.00
7	261.00	160.00	79.00	84.00
8	246.00	162.00		
9	252.00	164.00		
10	248.00	158.00		
11	248.00	169.00		
12	236.00	164.00		
Average	252.83	164.17	82.00	86.86

Cost Per Operation

Bearing	1st Op Cost/Part	2nd Op Cost/Part	3rd Op Cost/Part	4th Op Cost/Part	TOTAL Cost/Part	YEARLY Quantity	Total Yearly Labor Cost	1st Op Yearly Labor Cost	2nd Op Yearly Labor Cost	3rd Op Yearly Labor Cost	4th Op Yearly Labor Cost
MU5206XW888	$1.4363	$0.4219	$0.3469	$0.3365	$2.5416	12906	$32,801.89	$18,536.89	$5,445.04	$4,477.09	$4,342.87
MSN1211REX	$0.4711	$0.4907	$0.3290	$0.2962	$1.5870	9744	$15,463.73	$4,590.40	$4,781.38	$3,205.78	$2,886.17
MR1209EXW824	$1.2529	$0.4658	$0.4019	$0.2962	$2.4168	9009	$21,772.95	$11,287.38	$4,196.39	$3,620.72	$2,668.47
MR1211GEGX	$0.4711	$0.4907	$0.3290	$0.2962	$1.5870	7206	$11,435.92	$3,394.75	$3,535.98	$2,370.77	$2,134.42
MSN1308GEGX	$1.1324	$0.3499	$0.3840	$0.2692	$2.1355	4968	$10,609.16	$5,625.76	$1,738.30	$1,907.71	$1,337.39
MR1307EX	$0.2831	$0 4907	$0.3290	$0.2962	$1.3990	4515	$6,316.49	$1,278.20	$2,215.51	$1,485.44	$1,337.34
MR1307EXW3	$0.2831	$0 4907	$0.3290	$0.2962	$1.3990	4320	$6,043.68	$1,222 99	$2,119.82	$1,421.28	$1,279.58
MR1206EXW500	$1.4363	$0.8922	$0.5434	$0.3151	$3.1870	4200	$13,385.40	$6,032.46	$3,747.24	$2,282.28	$1,323.42
MS1310EXW1	$0.7852	$0.7852	$0.4816	$0.2742	$2.3262	3858	$8,974.48	$3,029.30	$3,029.30	$1,858.01	$1,057.86
MU1211X	$0.4711	$0 8412	$0.5106	$0.2962	$2.1191	3465	$7,342.68	$1,632.36	$2,914.76	$1,769.23	$1,026.33
MU1307X	$0.2831	$0.4907	$0.3290	$0.2962	$1.3990	3000	$4,197.00	$849.30	$1,472.10	$987.00	$888.60
MU1308X	$1 1324	$0.3499	$0.3840	$0.2692	$2.1355	2559	$5,464.74	$2,897.81	$895.39	$982.66	$688.88
MR1309EX	$0.2831	$0.4173	$0.3449	$0.2391	$1.2844	1140	$1,464.22	$322.73	$475.72	$393.19	$272.57
M1211GEGX	$0.4711	$0.4907	$0.3290	$0.2962	$1.5870	21	$33.33	$9.89	$10.30	$6.91	$6.22
Part Total							$145,305.67	$60,710.22	$36,577.26 $97,287.48	$26,768.06	$21,250.13 $48,018.19

Cost Saving for machine $84,595.45 Year One
Total - 1st Op Labor

PV of Savings

Total Yearly Cost $100,000.00
Monthly Cost $8,333.33
Yearly/12 Months

Months of Savings 24
Rate of Return 15.00%

Present Value of Sa $145,990.18

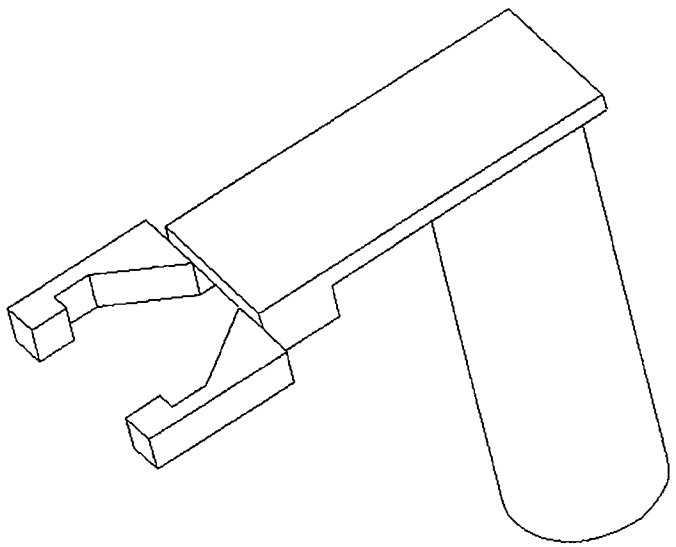
Appendix 3 – Cost of Machine Fabrication

Estimated Cost of Machine Fabrication

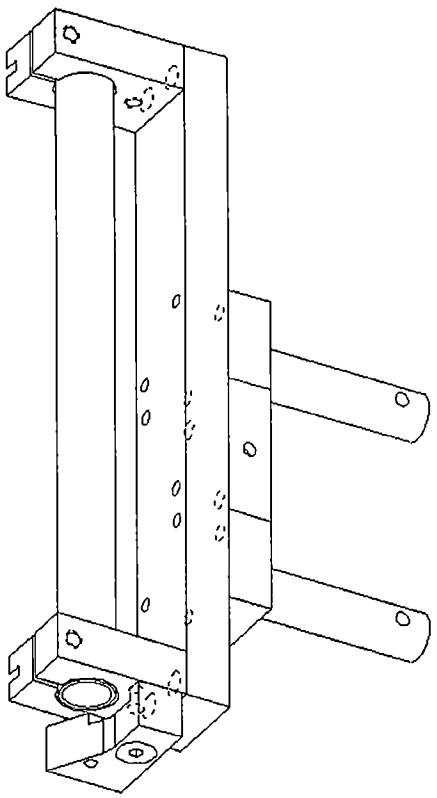
Part	Quantity	Cost	Total
Bowl feeders	2	$10,000.00	$20,000.00
Cylinders, Couplers, etc	11	$100.00	$1,100.00
Rotary Actuators	2	$1,300.00	$2,600.00
Solenoids, etc	13	$100.00	$1,300.00
Fiber Optic Sensors	8	$100.00	$800.00
Reed Switch, Cords, etc	30	$100.00	$3,000.00
PLC	1	$3,000.00	$3,000.00
Programming (HRS)	80	$30.00	$2,400.00
Part Specific Tooling	10	$5,000.00	$50,000.00
Fabrication Time (HRS)	640	$15.00	$9,600.00
Raw Material	1	$10,000.00	$10,000.00
Total			$103,800.00

Total Yearly Cost	$100,000.00
Monthly Cost Yearly/12 Months	$8,333.33
Months of Savings	24
Rate of Return	15.00%
Present Value of Savings	$171,868.62

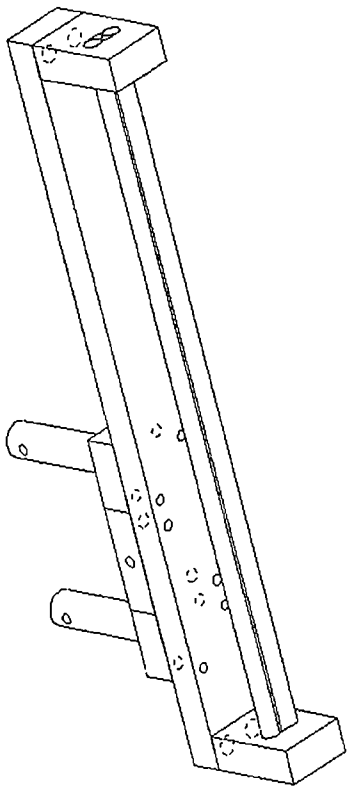
Appendix 4 – End Ring Loader Concept



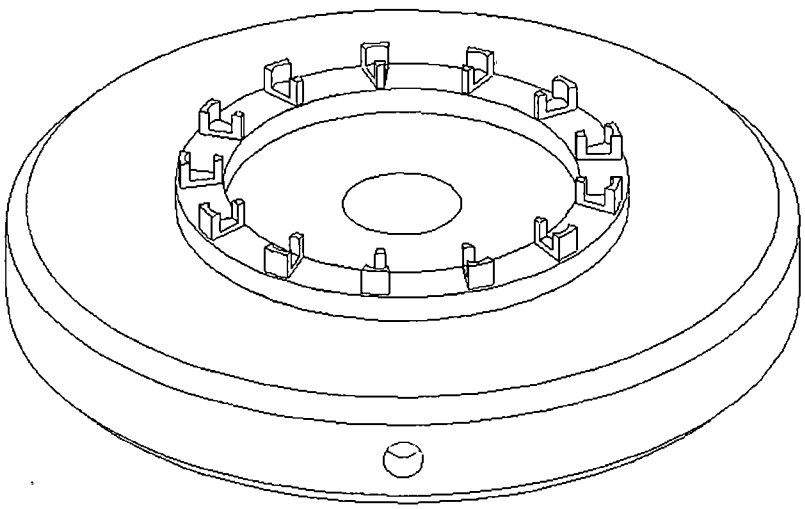
Appendix 5 – CX-16000-101 – Roller Loader



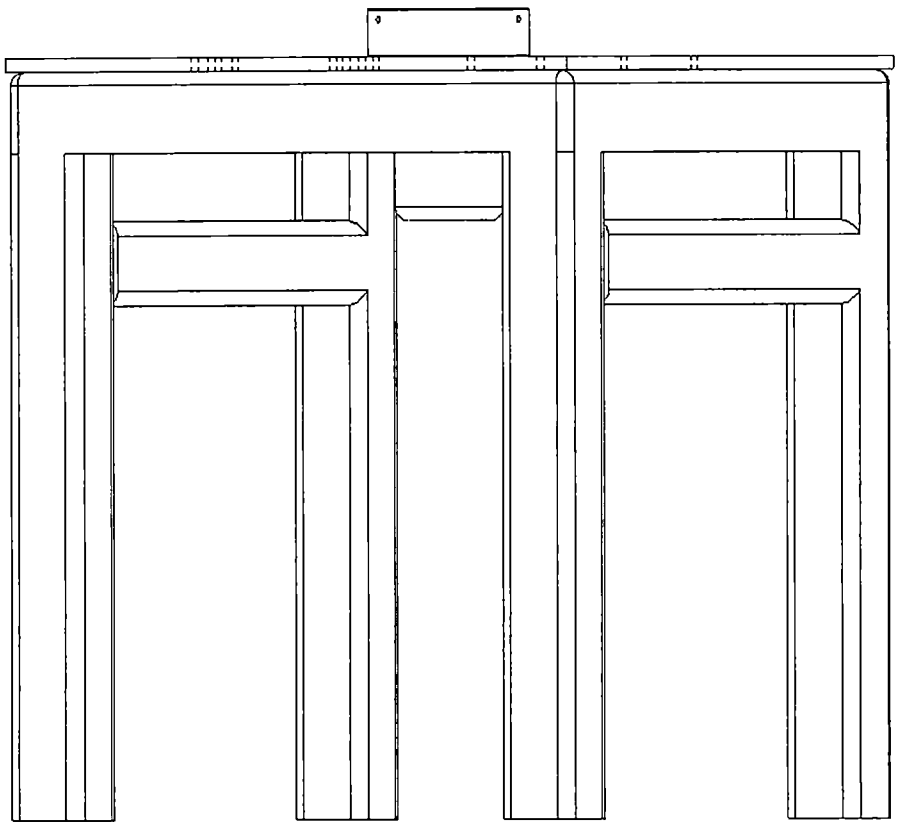
Appendix 6 – CX-16000-102 – Segment Loader



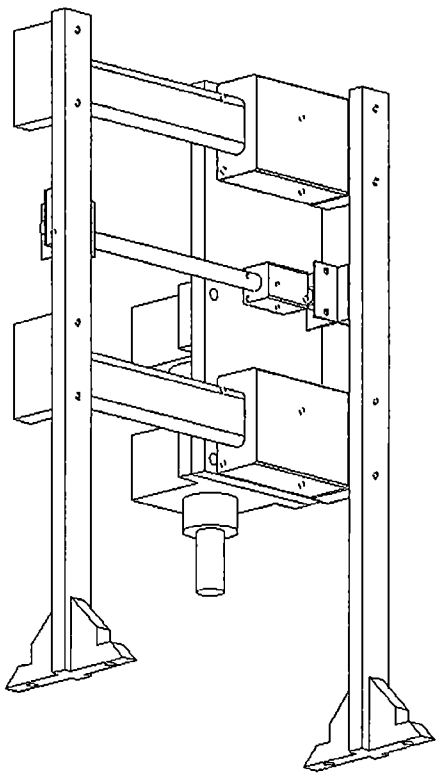
Appendix 7 – CX-16000-103 – Build Fixture



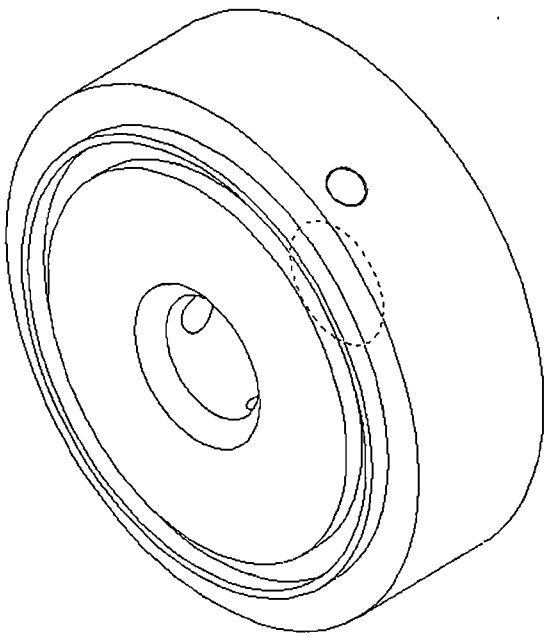
Appendix 8 – CX-16000-104 – Machine Base and Build Fixture Rotation Mechanism



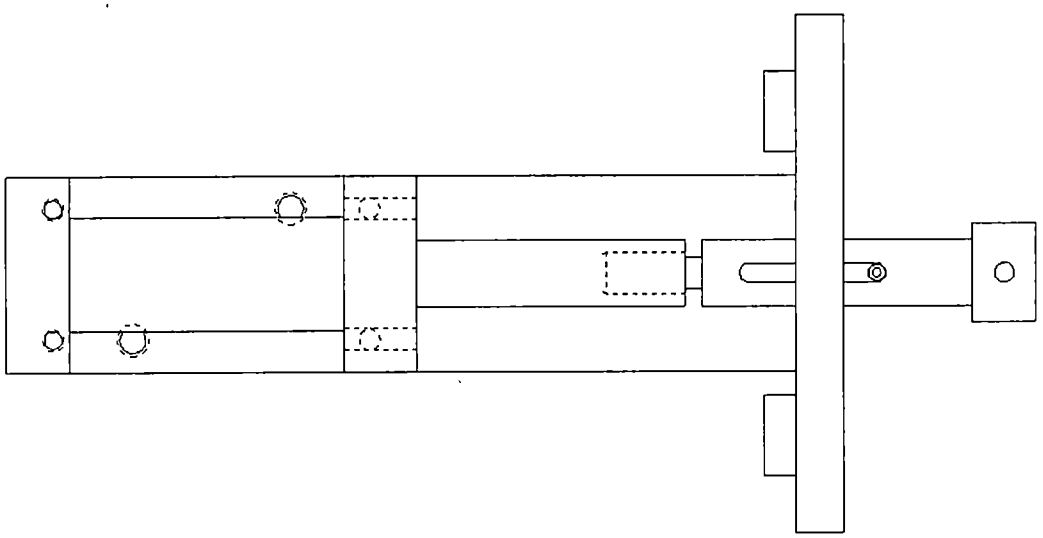
Appendix 9 – CX-16000-105 – End Ring Ram and Linear Slide



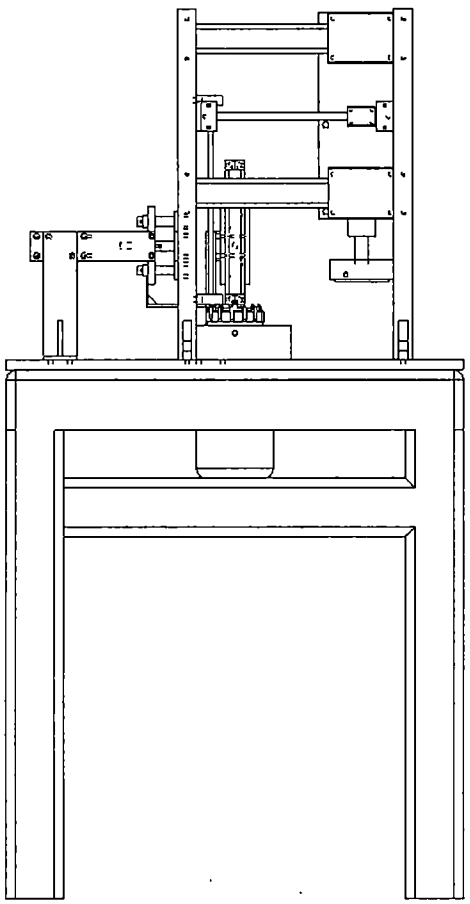
Appendix 10 – CX-16000-106 – End Ring Ram Fixture



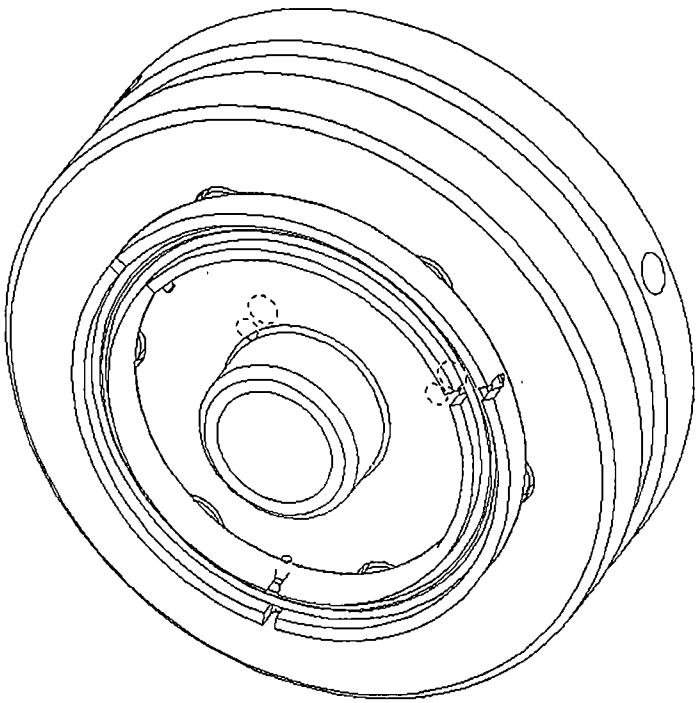
Appendix 11 – CX-16000-107 – Segment and Roller Loader Linear Actuator



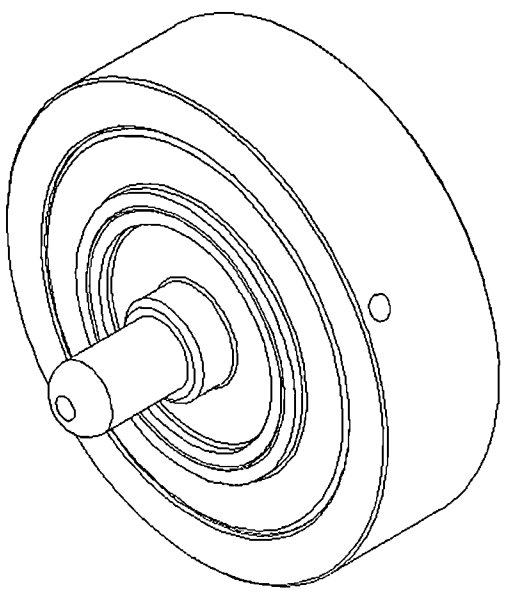
Appendix 12 – CX-16000-201 – Roller and Segment Insertion Machine



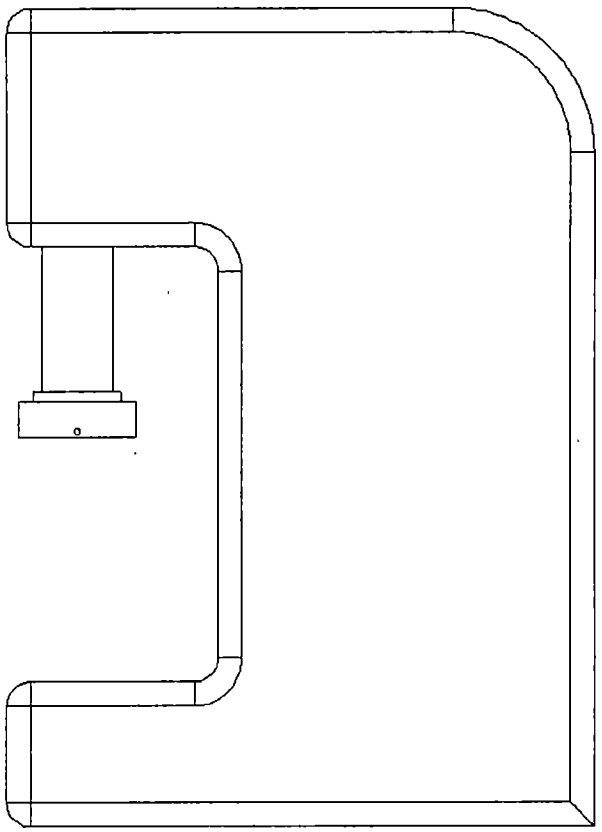
Appendix 13 – CX-16001-101 – Bearing Press Top Fixture



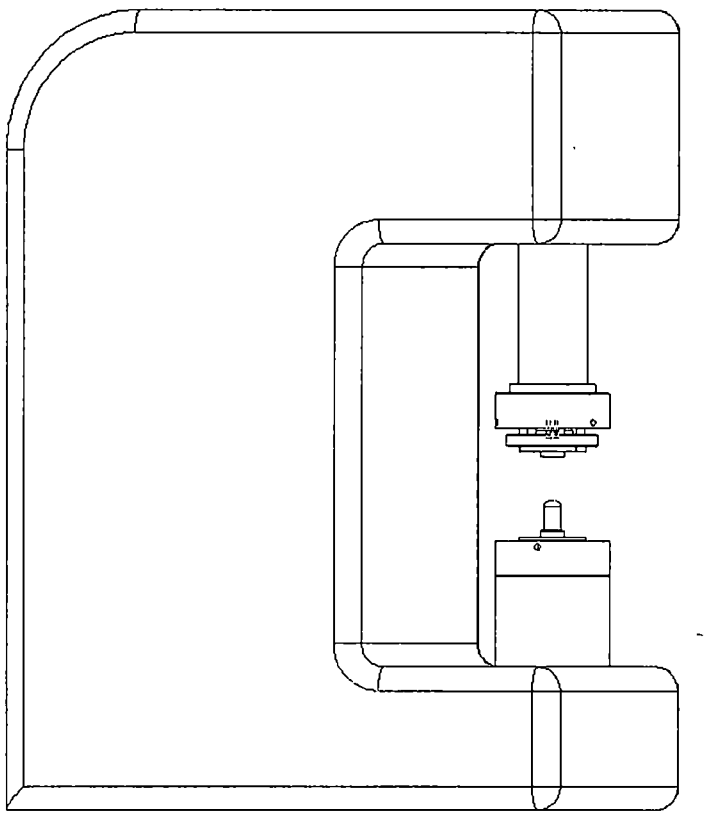
Appendix 14 – CX-16001-102 – Bearing Press Bottom Fixture



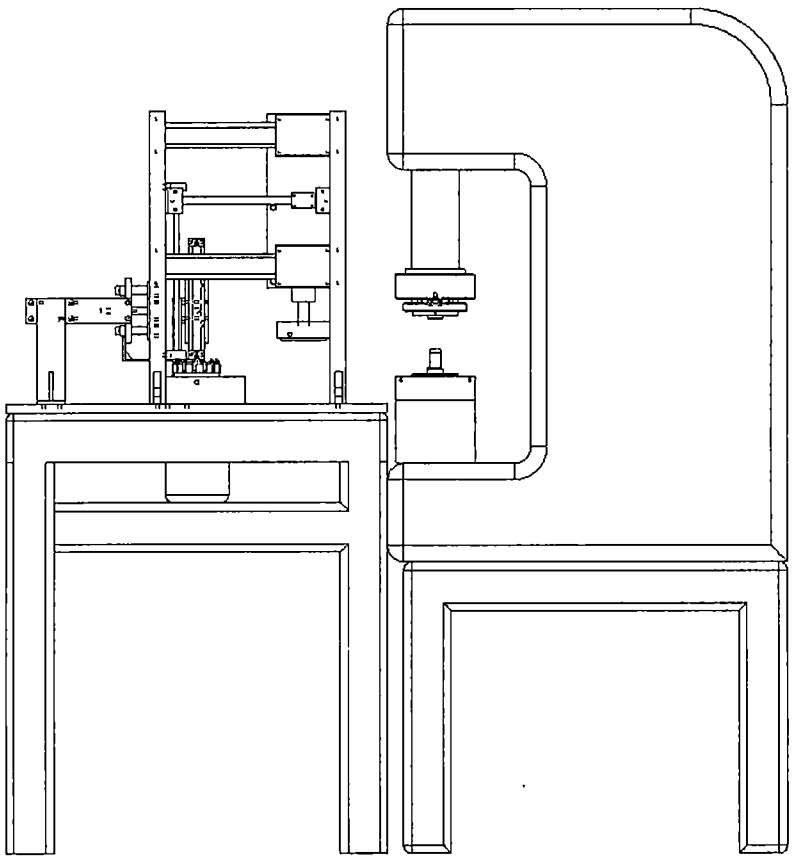
Appendix 15 – CX-16001-103 – Hydraulic Press



Appendix 16 – CX-16001-201 – Bearing Press Machine



Appendix 17 – CX-16000-301 – Machine Assembly



Vita

Nathan Baker was born in Fairfax, Virginia at a very young age. He attended public school in the Fairfax County public school system, and graduated from Robinson High School in June of 1993. Nathan attended the University of Tennessee in the College of Mechanical Engineering from August 1993 until May of 1999. Towards the end of the undergrad years Nathan cooped for three semesters with Link-Belt Bearings. In May of 1999 Nathan earned a Bachelor of Science in Mechanical Engineering with a Minor in Business Administration. December of 1999 Nathan began working full time at Link-Belt Bearings while completing school part time. In June of 1999 he began to pursue a Masters of Science in Mechanical Engineering part time while still working full time at Link-Belt Bearings. The Masters degree was received May 2001.