

Chapter 2: Design Problem, Constraints and Preliminary Concepts

2.1 Design Problem and Specifications

It is the objective of this thesis to evaluate the double row ball bearing assembly optimization process as broadly as possible. As mentioned in chapter one, however, the focused example is taken from Torrington's 5203 double row ball bearing process. As a general problem statement, it can be said that,

The Torrington 5203 double row ball bearing is currently being assembled manually which is, in itself, a tedious process. The current assembly process requires a special rubber O-ring and a machined groove into which the O-ring sits that serves no purpose other than to aid in the bearing assembly. In the assembly process, the O-ring supports the upper eight balls temporarily until the two rings can be aligned concentrically thus snapping the balls into the bearing races. This O-ring and its machined groove cost approximately 3 to 4 cents per bearing, thus adding substantially to the assembly cost of the bearing. If a retractable or reusable assembly component to support the upper balls during assembly can be design and implemented, it could eliminate the need for the O-ring and its groove and thus reduce assembly cost and time.

This thesis attempts to develop an assembly process and support device to eliminate the need for the ball support O-ring. In doing so, design requirements or specifications are needed. The bearing geometry, assembly space, fixture configuration, and human factors help to determine the requirements.

2.1.1 Introduction to Bearing Assembly Constraints

The two main areas that impose design constraints on the support device are the bearing geometry and the intended function of the support device. Other considerations include human factors, and current assembly station conditions.

The support device must function within the space available inside the bearing during assembly. The support device must fit into the clearance between the inner and outer ring of the bearing, without interference with either ring once it is in a stable position. The height of the support device structure must be specified such that the balls

that will be supported sit at the upper race of both the inner and outer ring. Since the support device is to be positioned after the lower eight balls are inserted, it must have extension or underneath clearance for these balls to remain properly seated. Also, due to the already inserted lower balls, limited clearance is available for the insertion of the support device. Yet another constraint dictated by the lower eight balls is the requirement for the support device to be inserted opposite the lower eight balls (see figure 2.1) and, through some actuation or geometric change, moved to the proper height to support the incoming top row of balls. The device of the support structure must obviously support the minimum number of balls needed for successful bearing assembly.

Human factors must also be considered. The support device must be designed such that its motion will not require unnatural positioning of the assembly person's hands and arms during bearing assembly or add to the potential for repetitive motion syndrome. No excessive force should be required and, ideally, an automated process is preferred.

Assuming it is to be used in the new assembly process, the current assembly station also imposes some design constraints. Because the assembly station is located on a bench, access to the bearing during assembly is limited. The support device may either be introduced into the bearing from above the workstation or from below the workstation, via an opening in the workbench.

These constraints are introduced as the general framework around which the support device is to be designed. The following sections serve to quantify these constraints.

2.1.2 Bearing Space and Insertion Clearance Constraints

The location and amount of space in which the support device can move within the bearing changes during the assembly process. The entry clearance also is different depending on the orientation of the bearing relative to the support device.

The support device can either be designed for insertion from the top of the bearing assembly or from the bottom, through the base of the assembly workbench. At this point in the assembly process the lower eight balls would have been inserted and the inner ring maintained at a tilted angle. These first eight balls limit the insertion clearance from the bottom of the bearing. The radial clearance between the inner and outer rings is 0.1657

inches and the angular clearance is 144 degree maximum. These values were calculated from the bearing geometry and the graphic representation of the bearing illustrated in figure 2.1. Greater clearance exists for the support device to be inserted from the top of the bearing assembly. This additional clearance is due to the tilted position of the bearing inner ring. Because of the manual assembly process, there are variations in the tilt of the inner ring, thus causing slight variations in clearance. With a maximum inner ring tilt, the clearance is 0.2966 inches and with a minimum tilt that just allows a single ball to be inserted at a time, the clearance is 0.2700 inches (Figure 2.2).

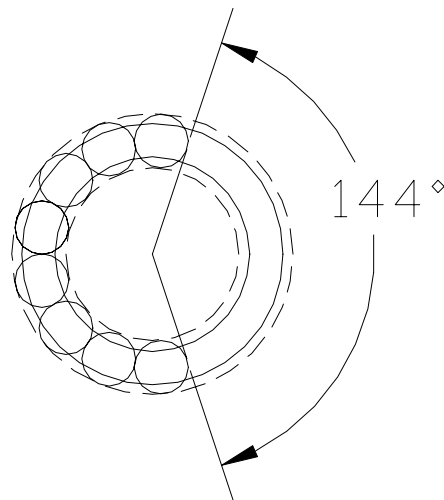


Figure 2.1 Eight balls as seated in bearing race, leaving 144° maximum clearance for support device insert.

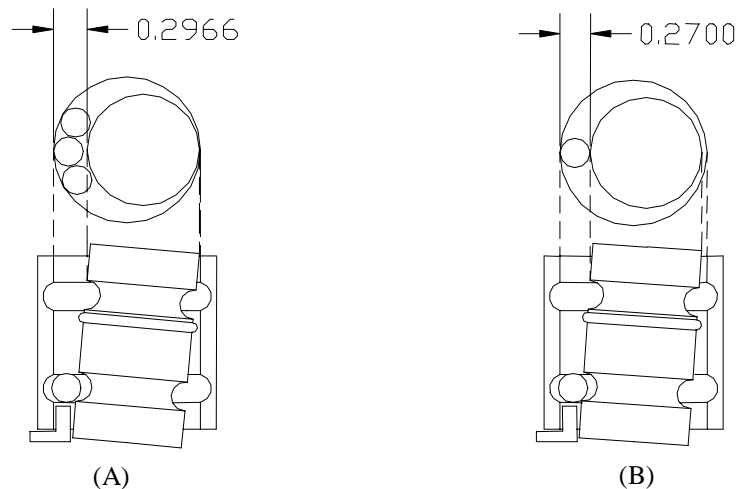


Figure 2.2 Variation in tilting angle produce different clearance. Maximum tilt (A) allows multiple balls to be inserted simultaneously and minimum tilt (B) only allows one ball to be inserted at a time.

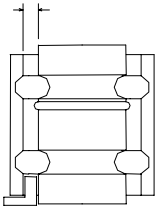
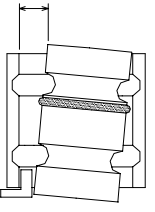
Clearance limitations are also produced by the bearing manufacturer tolerances listed in table 2.1. Based on these tolerances, maximum and minimum clearances are realized. The effect of the manufacturer tolerances on the clearance with the inner ring not tilted and tilted are presented in table 2.2.

Table 2.1 Manufacturer tolerances

Component	Dimensions and Tolerances(in)
Outer ring inner diameter	1.2930±0.0050
Inner ring outer diameter	0.9615±0.0010
Outer ring inner diameter at race seat	1.3887±0.0007
Inner ring outer diameter at race seat	0.8549±0.0007
Ball diameter	0.265625*

* No tolerance given on drawing

Table 2.2 Effect of manufacturer tolerances on ball insertion clearance.

		Inner ring, not tilted	Inner ring, tilted
			
Ball Insertion Clearance(in)	Minimum	0.1627	0.2906
	Maximum	0.1687	0.3026

2.1.3 Ball Support and Motion Constraints

There are two additional areas that dictate the design and construction of the support device, the motion required for it to complete its desired function and the number of balls it needs to support.

The double row bearing is designed such that the snap angle allows a maximum of eight balls to be inserted into each race. In the current configuration with the O-ring

support, the balls remain aligned with the upper race as they are inserted into the bearing during assembly. Essentially the O-ring forces the balls into the race by reducing the clearance below the race. It can be observed that only a small reduction in clearance is needed, approximately 0.027 inches, so that the balls will not pass through the bearing. Therefore, it can be said that only a certain number of balls need to be supported during assembly. A comparison between the clearance reduction accomplished by the O-ring and the clearance reduction (ball support) by a support device is illustrated in figure 2.3. It can be seen in figure 2.3b that the O-ring must support three of the eight balls whereas the support device must support four of the eight balls inserted.. This is because the O-ring prevents the inner ring from being tilted as far as it is allowed without the O-ring.

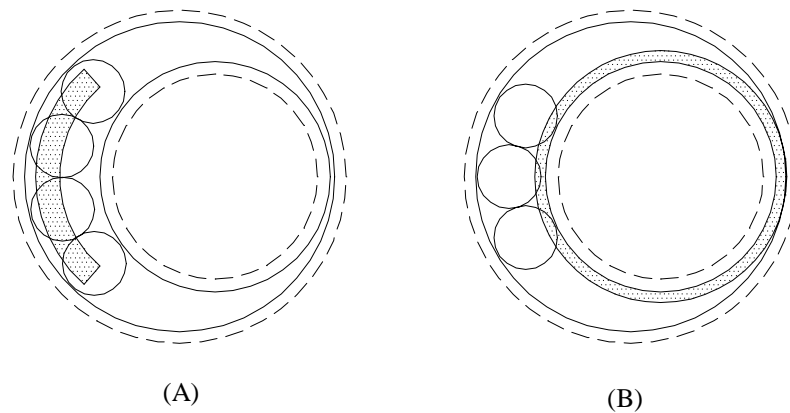


Figure 2.3 Comparison of the bearing with support device (A) versus currently used rubber O-ring (B). Dashed lines represent seats of bearing races.

The support device motion is also a determining factor in its design. The motion of the support device may be complex, especially if the device approaches from beneath the bearing assembly. Because of its complexity, consideration must also be given to whether the support device motion should be automated or implemented as a manual process.

The motion can be evaluated in three distinct sections, the initial position or entry, intermediate rise and/or rotation, and final support position. Reversal of these steps will result in removal of the support device from the bearing assembly.

As illustrated in figure 2.1 the entry of the support device is limited to a radial clearance of 0.1657 inches and 144 degrees. The entry or initial position of the support device can be one of three states, external to the bearing assembly or inserted in one of two positions, aligned with the lower race and balls, or just above the lower race allowing the lower balls clearance underneath. Figure 2.4 shows these three initial position options for the support device on a developed view of the bearing.

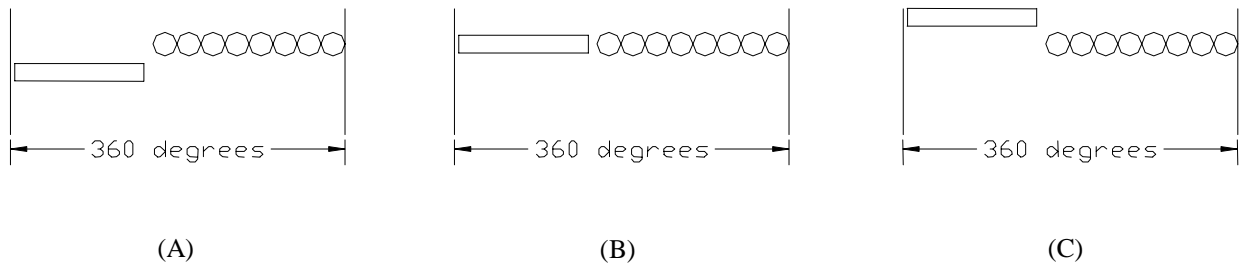


Figure 2.4 Three options for the support device initial position. (A) External or below bearing assembly, (B) aligned with lower race and balls or (C) above lower race allowing clearance for lower balls. Bearing illustrated here is a developed view with the bearing laid flat.

The intermediate motion of the support device is the most complex portion of its movement. From the initial position to its final support position the device must have a combination of axial motion into the bearing and rotation about the bearing centerline, possibly simultaneously. The initial position dictates its first motion, whether axial or rotational. If the initial position is external to the bearing assembly or internal, aligned with the lower race and balls, the initial motion will need to be axial. Otherwise, the first motion will need to be a rotation. Since the support device originates opposite of where the balls are to be inserted, it must rotate through 180 degrees.

After the support device has completed this motion sequence, it should be seated at its topmost position, just below the upper race of the bearing. With the inner race tilted, the device should be centered in the resulting clearance. Now the upper eight balls can be inserted into the bearing assembly.

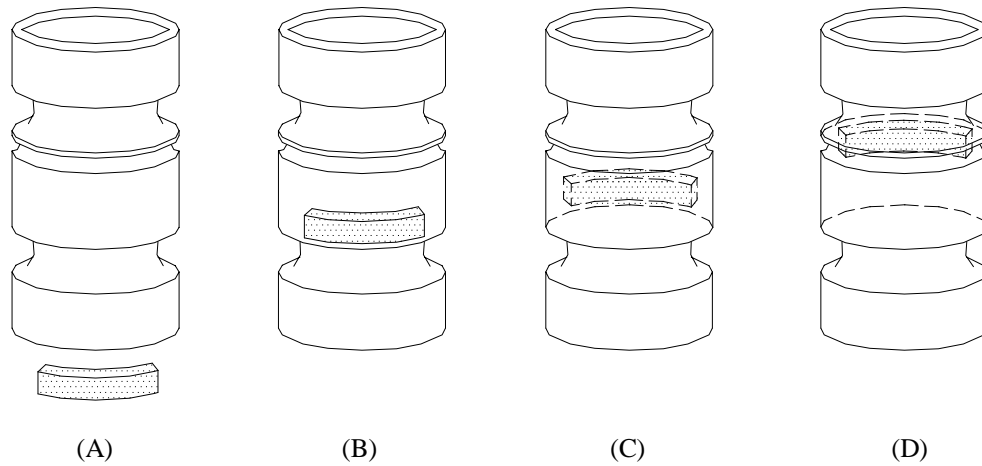


Figure 2.5 (A) Initial position of support device outside of bearing, (B) support device after first axial motion, above lower race, (C) after 180 rotation, support is above lower eight balls, (D) final position of support device just below upper race.

2.2 Preliminary Design Concepts

Once the design specifications had been determined, broad design ideas were developed. This process was not undertaken to determine a specific design, but rather as an unrestricted platform for generating possible design solutions. These ideas are presented in the form in which they were initially developed and are categorized in two functional groups, namely, structured support and non-structured support. The structured support concepts consist of solid structures on which the balls can rest during bearing assembly. The non-structured support concepts are devices or substances that may change physical shape during or after bearing assembly. Non-structured support concepts also include assembly techniques that may not physically support the balls and/or may require assembly station motion. Figure 2.6 gives an overview of the initial design concepts. Following figure 2.6, a brief description of each concept design is presented with a preliminary sketch, where applicable.

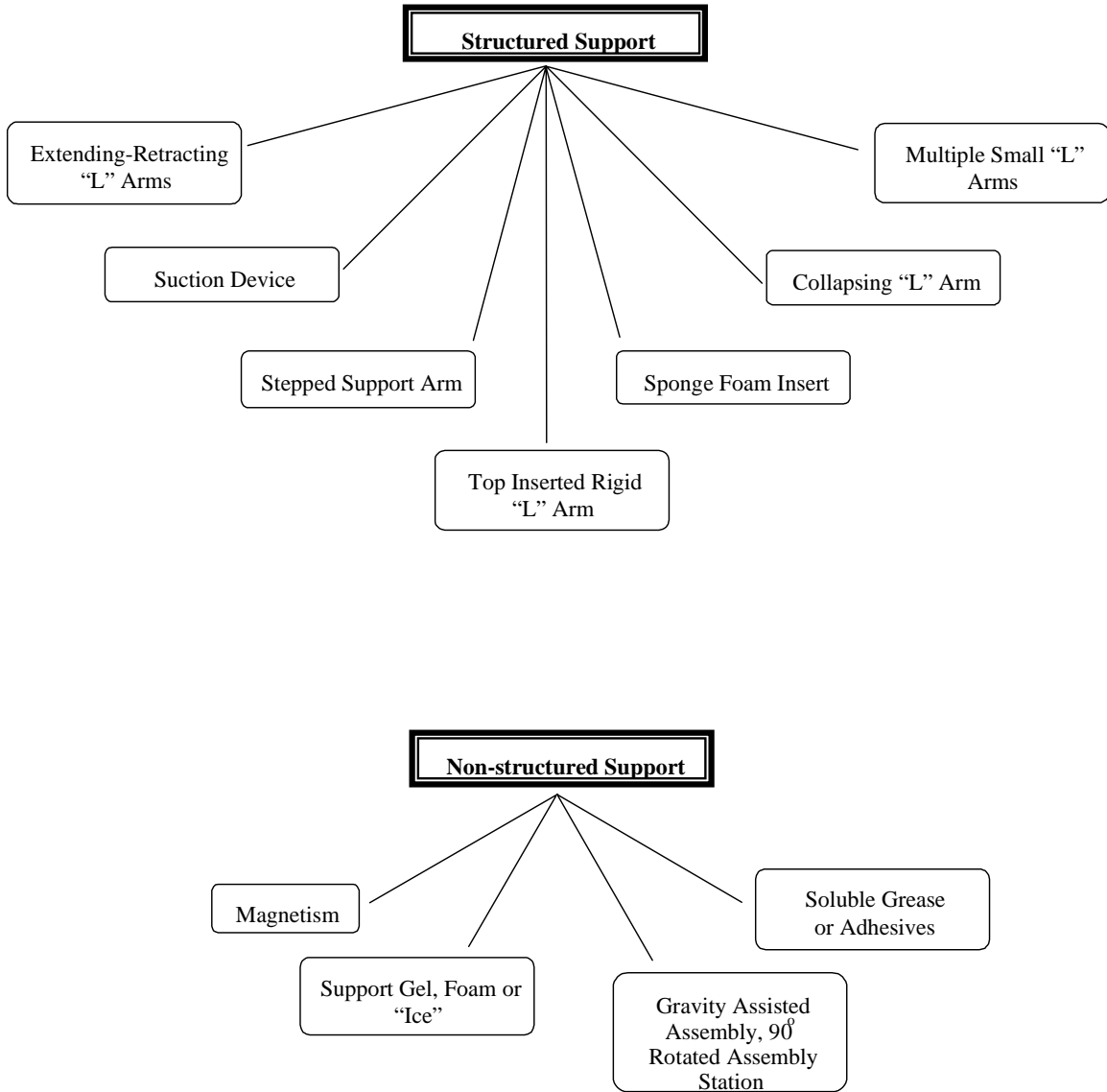


Figure 2.6 Overview of all initial design concepts.

Soluble grease or adhesives: A soluble grease or adhesive could be used to temporarily attach the balls to the race of the inner ring. Theoretically, with the proper clearance, by distortion of the outer ring, the inner ring could be inserted with the balls intact. After snapping the balls into place, the bearing would be rinsed of the “assembly grease” before further processing.

Magnetism: This concept is similar to the water-soluble grease or adhesive. The inner race could be magnetized so that the balls are magnetically attracted to it. While the balls adhere to the inner ring race, the inner ring could be inserted into the outer ring.

Once inserted and snapped into its assembled position, the magnetism would then be removed from the inner ring.

Support Gel, Foam or “Ice”: Since the balls only need support for a short period of time and are light weight, it may be possible to support them using a gel, foam or “ice” type substance. A gel or foam substance can be rinsed away after the bearing has been assembly in the same way as the support grease. “Ice” can be a variety of substances that have solid and liquid phases near room temperature and sufficient density to support the balls. Water ice is one conceivable “ice” substance. To avoid narrow temperature constraints during assembly, the substance may have properties such that it is solid at room temperature and liquid when heated.

Suction Device: This concept considers the option of inserting the balls from the top of the bearing assembly using a series of suction tubes that hold each ball individually for insertion, as shown in figure 2.7. Low suction requirements can allow for small tubes that will easily fit in the clearance between the inner and outer ring of the bearing. The suction can also provide ease of ball retrieval from a multiple ball bin. The compromise between tube flexibility and rigidity should be sufficient for proper seating of the balls into the bearing upper race during assembly.

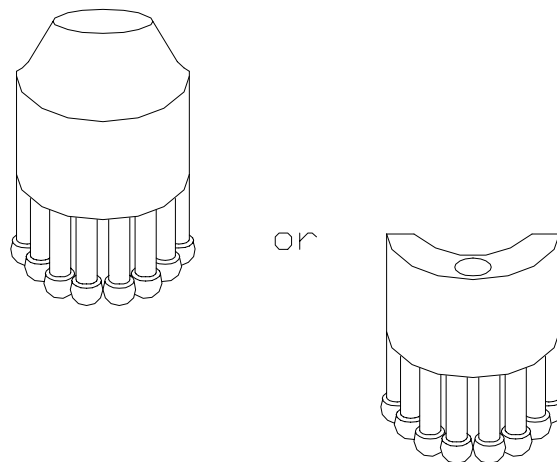


Figure 2.7 Suction device conceptual design for ball insertion

Extending-Retracting “L” Arms: In this case the balls are to be supported by two arms that will be extended from hollow arms. The extension arms are designed to be

hollow with a small fraction of their length bent to 90 degrees at the tip, as shown in figure 2.8. The hollow space is intended to contain a wire or flexible rod that can be extended to support the balls. The two rods are to be inserted at opposite ends of the previously inserted lower balls, i.e., ahead of ball one and behind ball eight, as shown in figure 2.8a. The bent sections or openings from which the arms are to extend are to be facing in towards each other so that the arms will position themselves above and across the lower eight balls. In the fully extended position the arms should meet, thus bridging the clearance between the inner ring and outer ring, figure 2.8b. Once the upper eight balls are inserted and snapped into place, the arms can then be retracted into the arm supports and the arm supports removed from the bearing assembly.

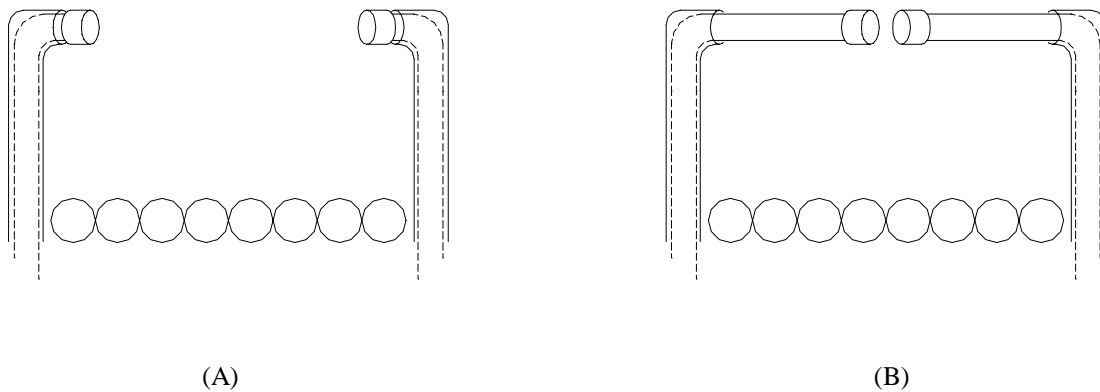


Figure 2.8 Extending-Retracting “L” Arms concept design

Collapsing “L” Arm: Another design concept for ball support inserted from the top of the bearing assembly is a collapsing arm. This arm would consist of multiple sections linked by an internal cord or “string”. When tension is applied to the internal cord, the segments are pulled together and are forced into a rigid “L” configuration to support the balls, as illustrated in figure 2.9a. Once the upper eight balls are inserted and the bearing snapped into position, the tension is then released from the internal cord. Without the tension, the segments are separate and can be removed from the bearing assembly, as shown in figure 2.9b.

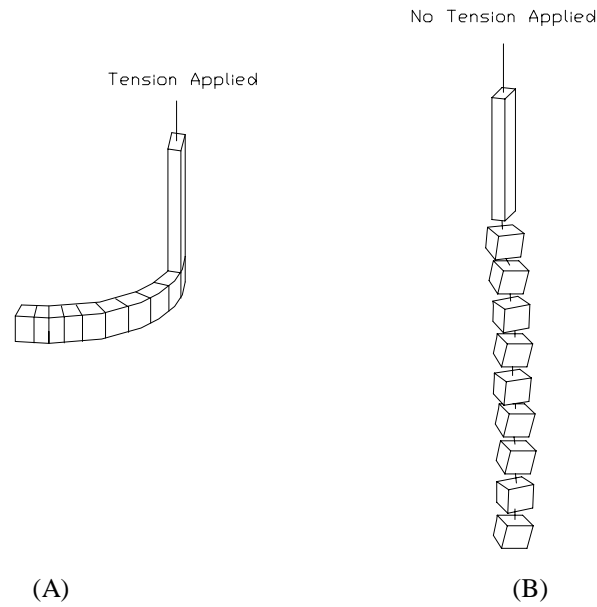


Figure 2.9 Collapsing arm conceptual design for ball support structure. (A) Tension applied when supporting balls, (B) No tension releases sections for ease of removal from bearing assembly.

Multiple Small “L” Arms: To support each ball individually from beneath, several L shaped arms can be inserted into the bearing assembly. The arms must be constructed of a thin material that can be inserted between the lower balls. During insertion, the horizontal section of the L arms will be oriented perpendicular to the inner and outer bearing rings, as shown in figure 2.10a. Once the arms are inserted to the proper height to support the upper row of balls, the arms are to be rotated such that the horizontal sections are aligned around the bearing ring assembly, as shown in figure 2.10b.

Top Inserted Rigid “L” Arm: The top inserted rigid “L” arm is similar to the collapsible “L” arm. The support arm is constructed with the same geometry as the collapsible arm, but, in this case, the arm is rigid. A mounting fixture or handle is included to maintain the proper position of the arm during bearing assembly, as shown in figure 2.11. After the upper eight balls are inserted and the bearing is snapped into the assembled position, the arm is rotated 180 degrees into the 144 degrees clearance and removed from the bearing assembly.

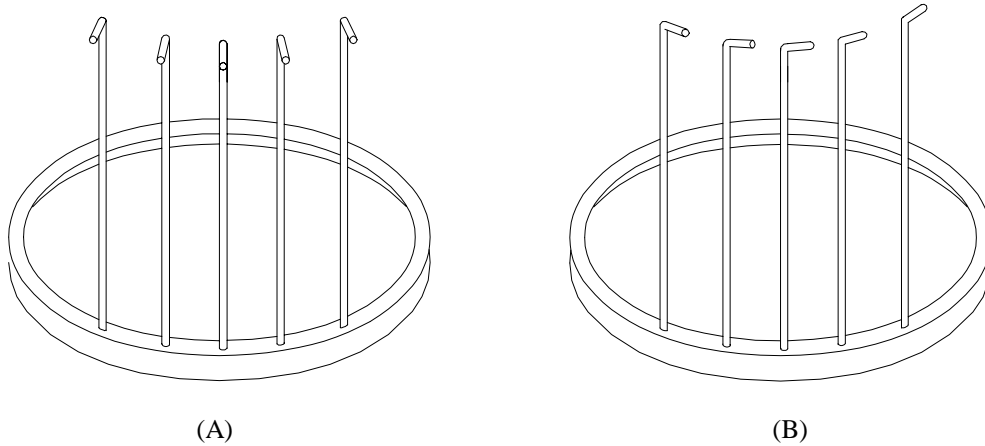


Figure 2.10 Multiple small “L” arms concept design, inserted to support ball during assembly. (A) “L” arms oriented perpendicular to rings for insertion into bearing assembly, (B) “L” arms rotated in alignment with clearance to support balls.

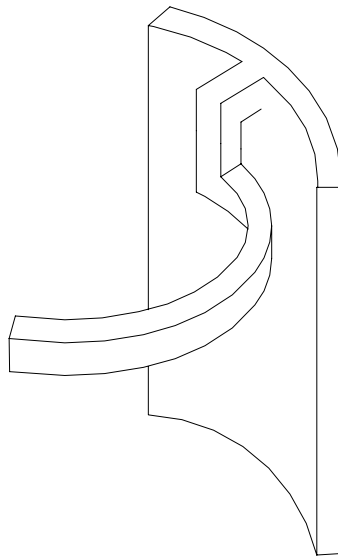


Figure 2.11 Top inserted rigid “L” arm with support fixture or face to provide proper seating in bearing assembly.

Stepped Support Arm: This design concept follows the idea of the original spiral model fabricated at Torrington in Calhoun Georgia, except instead of a spiral ramp structure it has a step structure. This concept is shown in figure 2.12. Once inserted into the bearing assembly from below, the motion should consist of discrete raising and

rotating steps. Simple reversal of the motion should remove the support structure from the bearing assembly after the balls have been inserted and properly seated.

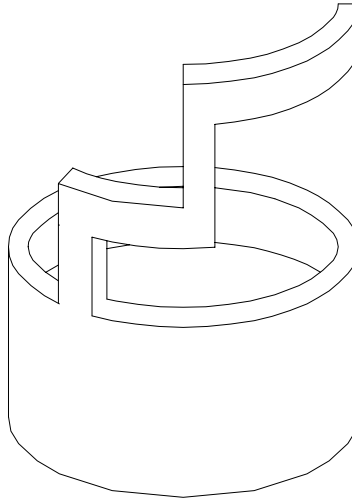


Figure 2.12 “Stepped” ball support arm design concept.

Sponge Foam Insert: A sponge foam type material of the proper size and density can be inserted after the lower balls have been placed into the bearing assembly. The material will be pliable enough to allow proper motion of the inner race for the assembly process but will be firm enough to support the inserted upper balls. Once the upper balls are inserted, the sponge foam material can then be removed by deforming it and pulling it through the opening. Proper material selection is critical to allow removal and reuse.

Gravity Assisted Assembly, 90° Rotated Assembly Station: One of two methods can be used. The first involves insertion of the lower eight balls as it is currently done and then rotating the assembly station 90° to insert the remaining balls. The second involves rotating the assembly station 90° and inserting both rows of balls with the station in this rotated position. The assembly station will be rotated about the axis perpendicular to the person performing the assembly. As in the currently assembly method, the bearing inner ring will be tilted so that the balls can be inserted into the bearing, however, the inner ring will be tilting towards the support edge instead of away from it. The support edge serves as a tilting point for the inner ring. A ball feeding tube will be used to insert the balls. This feeding tube will be equipped with barrier arms that prevent the balls from

rolling out of the bearing assembly, thus forcing them into the bearing races, figure 2.13. The tilted bearing makes use of gravity to force the balls around the circumference of the bearing race. If the bearing is to be assembled completely with the assembly station at 90° , the ball feeding tube can be used to fill both upper and lower races as illustrated in figure 2.14.

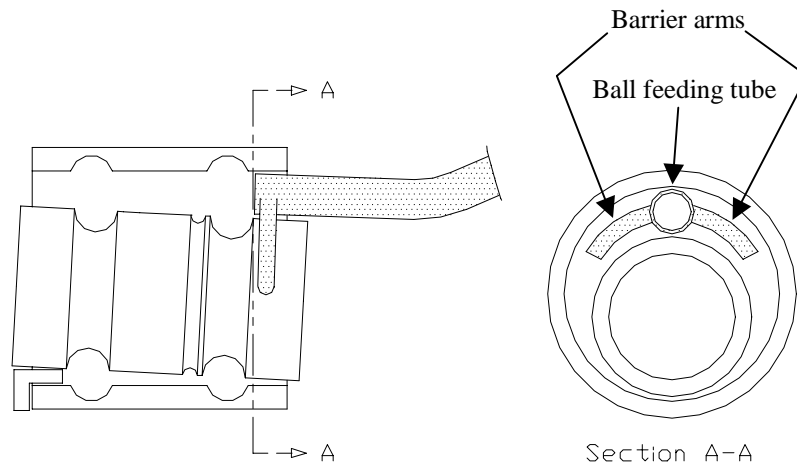


Figure 2.13 Gravity assisted assembly with assembly station rotated 90° . Section A-A shows the barrier arm that prevents the balls from rolling out of the bearing assembly forcing them into the bearing races.

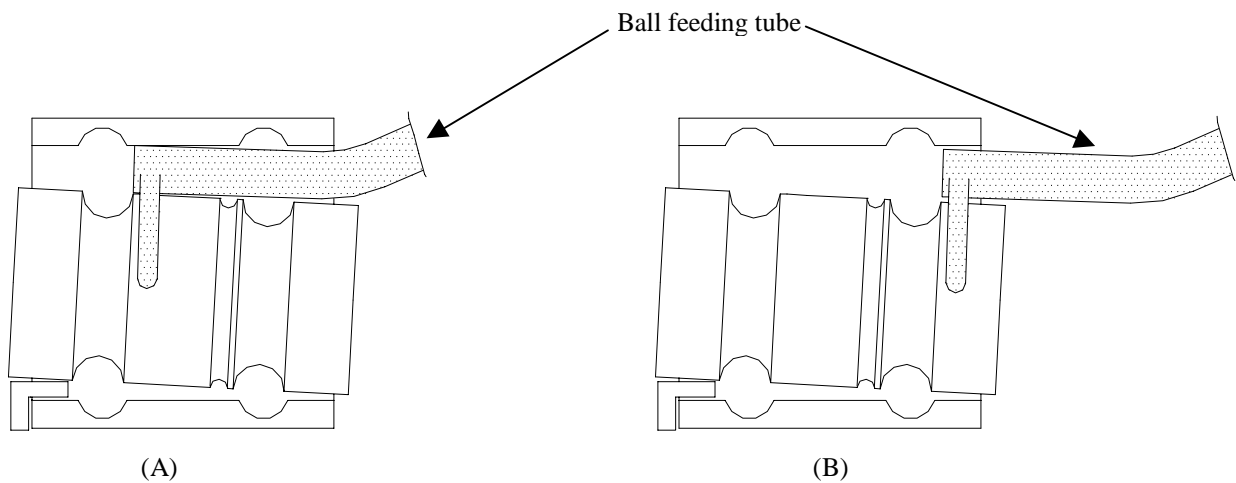


Figure 2.14 Gravity assisted assembly with assembly station rotated 90° . (A) Feeding tube inserted fully to insert balls into lower race, (B) Feeding tube inserted to fill upper race.

2.2.1 Preliminary Design Selection

The preliminary design selection was used to reduce the large group of broad concept designs based on a general list of requirement. The requirements included two major categories, structural integrity and functionality. Within the structural requirements are considerations of robustness in application, ability to accommodate the assembly clearance, and ease of fabrication. Ease of fabrication took into account prototyping and testing of the support arm structure. The functionality of the support arm structure had subcategories for its main function of supporting balls, freedom of the balls during insertion, actuation both into and out of the bearing assembly, and implementation of the support system into the current Torrington assembly station. Actuation also included any required motion of the support arm relative to itself. The following table presents a design score for each model for the aforementioned requirements. The following scale was used: 1-met requirements fully, 2-partially met requirements, 3-did not meet requirements, or 4-needs further analysis.

Table 2.3 Preliminary Design Selection

Conceptual Design Name		Structural			Functionality			Total	
		robustness	clearance	fabrication ease	ball support	ball freedom	actuation		implementation
Non-structured	Soluble grease or adhesives	3	3	1	2	3	1	4	17
	Magnetism	3	3	2	3	3	1	4	19
	Support Gel, Foam or "Ice"	4	1	2	4	2	1	4	18
	Gravity Assisted Assembly...	1	4	2	1	1	2	4	15
Structured	Suction Device	2	2	4	2	3	2	4	19
	Extending-Retracting "L" Arms	3	2	3	4	1	2	4	19
	Collapsing "L" Arm	3	2	3	2	1	4	2	17
	Multiple, Small "L" Arms	3	2	3	3	3	3	4	21
	Top Inserted Rigid "L" Arm	2	1	2	1	1	2	4	13
	Stepped Support Arm	2	1	1	1	1	2	4	12
	Sponge Foam Insert	4	2	1	2	1	1	2	13

The soluble grease or adhesives and the magnetism did not meet the robustness requirement due to their lack of structure. In both cases the balls were to be secured to the races of the inner ring prior to assembly and, in doing so, there is insufficient clearance for the combined ring and balls to be inserted into the outer ring. The pre-securing of the balls to the inner ring also reduces the balls' freedom of motion during assembly. Because the grease or adhesives needs to be applied and removed, implementing this procedure into the current assembly process needs further analysis. Magnetism is undesirable because it can cause the bearing to collect ferrous debris.

The support gel, foam or "ice" needs further analysis and design to determine its potential robustness. A major effort will be required because of the variety of substances that could be used.

Conceptually, the suction device would be robust and meet the clearance limit of the bearing assembly. However, implementation of a suction system also needs further analysis. The suction tubes are intended to hold the balls in alignment with each other as they would be in the bearing, see figure 2.7. In this position the balls are not free to properly seat themselves during bearing assembly.

Due to the small clearance and the dynamic requirements of the extending-retracting "L" arms, this concept fails to be sufficiently robust. Further evaluation may help overcome these concerns, however. Because the wire or flexible metal arms are to be inside the insertion arms, the fabrication of this device is complex. Similar problems occur with the collapsing "L" arm. Also with the collapsing "L" arm, the actuation may not produce accurate alignment of the sections when converting from segmented to rigid configuration.

For the multiple, small "L" arms to be inserted and then rotated they must be thin, thus lacking robustness. The small size will give it sufficient clearance in the bearing but add to the difficulty of its fabrication. Another factor in fabricating the small arms is the actuation system required for their individual rotation. After they have rotated into the proper position they may not sufficiently close the gap between each other, either trapping or not supporting the inserted balls.

The lowest scoring structured designs evaluated in the preliminary design selection were the top inserted rigid “L” support arm, the stepped support arm and the sponge foam insert. Each of these was carried over into the secondary design synthesis process. The lowest scoring non-structured design concept was the gravity assisted assembly, which was also carried over into the secondary design synthesis process. Both the top inserted rigid “L” support arm and the stepped support arm designs can be robust if constructed of steel or other strong metal. Durability of the sponge foam material will ultimately determine its robustness. Fabrication was expected to be relatively simple, both for prototyping and functional use, however, the top inserted rigid “L” arm may be slightly more difficult than the stepped support arm. Actuation will require both axial and rotational motion for both support arms. This motion is, however, less complex than other rigid-arm-type conceptual designs. Each of these designs needs further evaluation prior to their implementation into the current assembly process.

2.3 Preliminary Design Summary

This preliminary design selection served as a first evaluation of a wide variety of initial design concepts. Four concepts have met the design specification and theoretically function as required. Additional design synthesis is required for further evaluation. Chapter three will present the prototyping and testing of these designs. It will also include a discussion of previous design by Torrington line workers and Research and Development engineer, Jim Buchanan.