NATIONAL RADIO ASTRONOMY OBSERVATORY
Socorro, New Mexico

VLBA Antenna Memo 96

VLBA Owens Valley Gearbox Repair

December 9th-12th 2014.

Prepared by
Michael Romero
12/17/14

1. BACKGROUND

On October 16th, the Owens Valley site reported that the Az #1 gearbox was making a grinding noise when it was operated at high speed slew. The preload direction was changed, but it had no effect on the gear box noises. With the recommendation of Eric Carlowe, the slew speed was slowed down, which decreased the noise coming from the gearbox substantially. The antenna was to remain operating in slow slew until a team could be assembled and sent out to repair the problem.

On December 9th 2012 Dan Haggenmiller and Michael Romero left for Owens Valley with a complete gearbox and additional spare parts to repair the problem at any stage of the gearbox. Jon Thunborg arrived at the site December 11th to aid with the repair.

2. GEARBOX TEARDOWN

The first stage housing was removed from the gearbox. When the housing was removed, there were no visual signs of the failure mode. The sun and three planetary gears were then removed from the first stage. Removing the gears revealed that a thrust washer was broken on one of the three gears. Additionally, the other two thrust washers were badly deformed and were probably next to fail. Figure 2.1 details the first stage after the first stage housing and gears were removed.

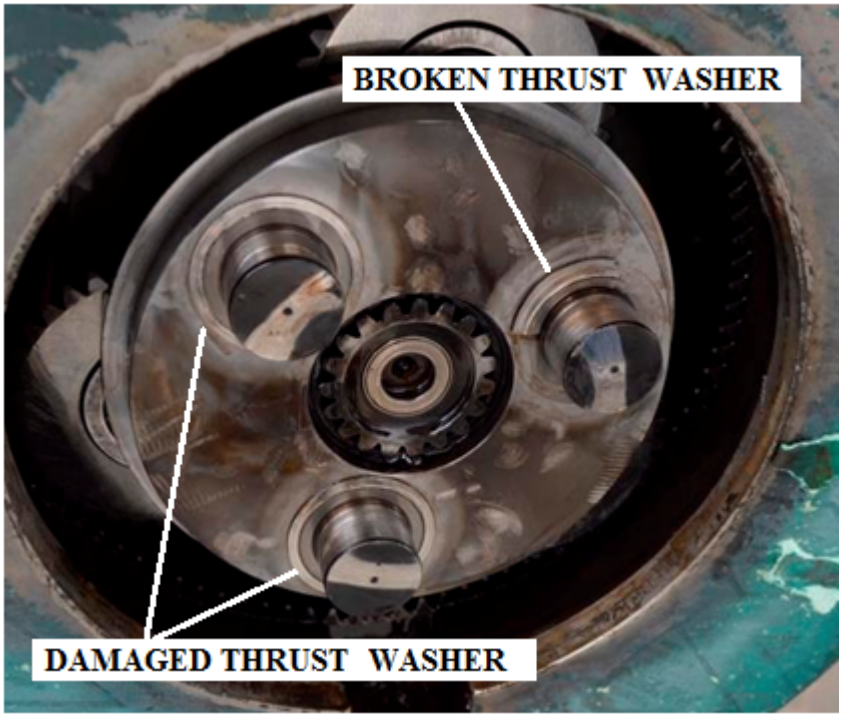


Figure 2.1: Damaged Thrust Washers

The first stage was removed and the second stage inspected. The second stage gears were removed and inspected. No abnormal wear or problems were found when inspecting the second stage. With the second stage removed, the remaining stages were inspected visually for signs of wear or failure. There were no problems found during inspection. Figure 2.2 details the second stage with the sun gear and upper planetary gear removed.

Figure 2.2: Second Stage

The inner stages were cleaned and searched for metal or other foreign material. A small amount of foreign material was found and removed, but no metal from the thrust washer was found. Figure 2.3 details the gearbox with the second stage removed.

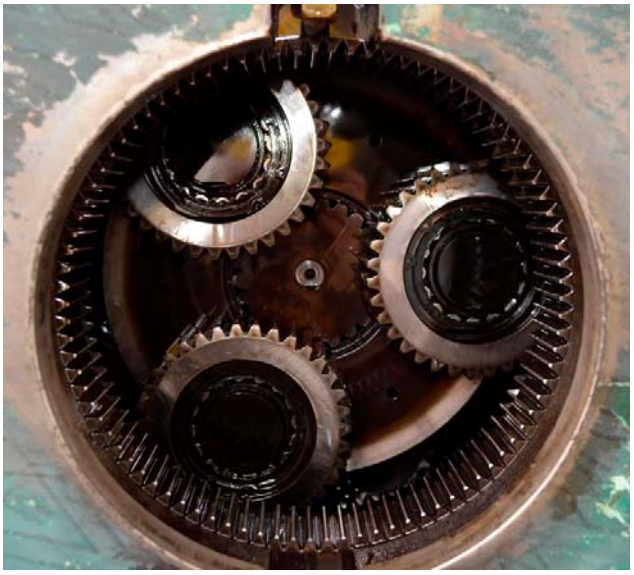


Figure 2.3: Inside Gearbox w/o Second Stage.

3. GEARBOX REASSEMBLY

The second stage was cleaned and re-installed in the gearbox using a new thrust bearing. Figure 3.1 details the second stage re-installed in the gearbox.

Figure 3.1: Second Stage Re-Installed

A new first stage was then installed using a new thrust bearing as well. Figure 3.2 details the new first stage installed.

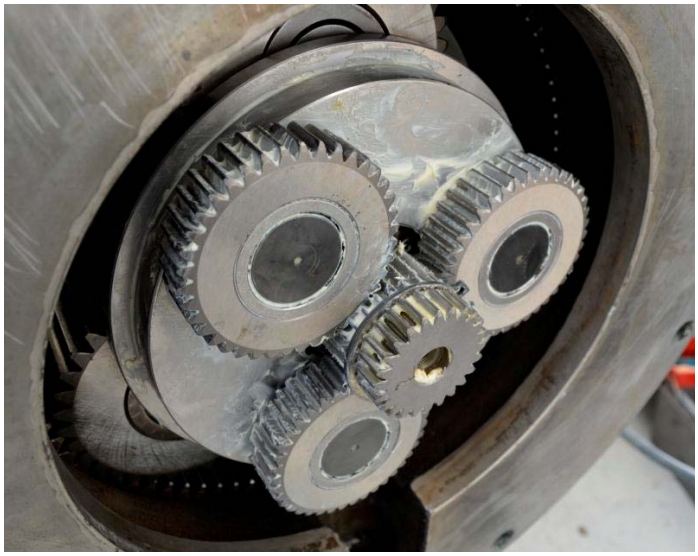


Figure 3.2: New First Stage Set Installed

Due to excessive scoring in the thrust ring grove, the spare first stage housing, with input shaft and bearings, would be used. Once the new first stage gears were installed, the measurement tool was installed following procedures outlined in the VLBA Compower Gearbox Axial Clearance Adjustment Procedure Measurements Calculation Sheet (see Appendix A). Figure 3.3 details the measurement tool on the first stage.

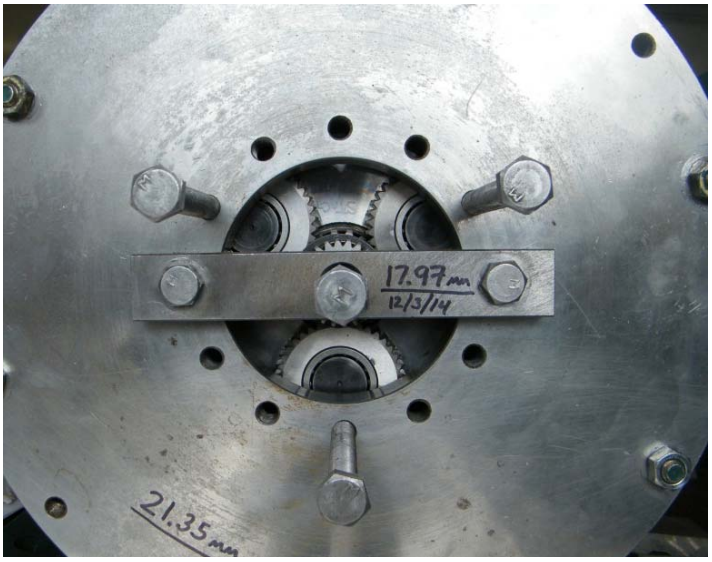


Figure 3.3: Installed Measurement tool

Following the above mentioned procedure, table 3-I was filled out.

Table 3-I
Initial Measurement Values

Measurement	Value (mm)
T1	21.35
T2	17.97
A	7.82
B	19.99
C	26.92
D*	27.30
E	37.57

*Determined following procedure on pages 5-7 in Appendix A:

From the values above, G and H were calculated using the following formulas.

$$G = D - T1 - C + B$$
$$H = E - T2 - T1 - C + A + B$$

Table 3-II
Calculated G & H Values

Distance	Value (mm)
G	-0.98
H	-0.86

The values of G and H were both negative, meaning that a gasket would be needed to avoid interference between the first stage gears and housing. Figure 3.4 details G and H dimensions.

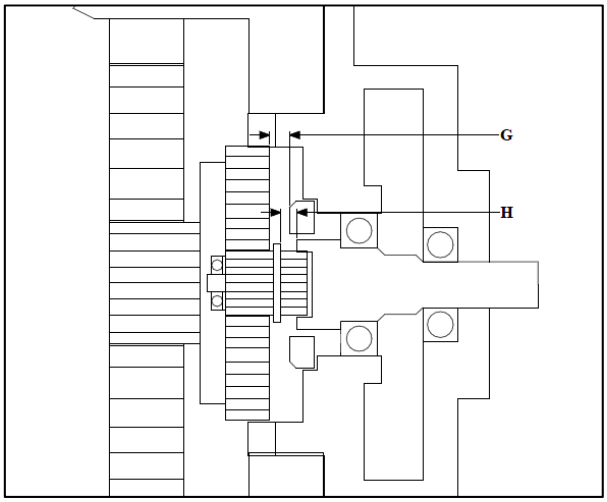


Figure 3.4: G and H Dimension Detail

Additionally, G<H, meaning the thrust ring would contact the gears before the thrust bearing. In order to prevent this, a 1mm shim was added to the first stage sun gear. Table 3-III details the measured and calculated values after the 1mm shim.

Table 3-III
1mm shim Measurement Values

Measurement	Value (mm)
T1	21.35
T2	17.97
A	7.82
B	19.99
C	26.92
D*	27.30
E	36.53
G	-0.98
H	-1.98

Adding the 1mm shim decreased the value of E, making G>H. This means that the thrust bearing will contact before the thrust ring, as designed.

The gasket thickness, K, was then calculated to bring the values of G and H positive.

$$K = 1mm - H$$
$$K = 1mm - (-1.98mm) = 2.98mm$$

The ideal gasket size is 2.98 mm.

Table 3-IV details the gaskets used to make the 2.98mm thickness.

Table 3-IV
Gasket Thickness Measurements

Gasket	Advertised Thickness (in)	Advertised Thickness (mm)	Actual Thickness (mm)
1	1/16”	1.59	1.55
2	1/32”	0.79	0.72
3	1/32”	0.79	0.72
Total		3.17	2.99

The following table details the measured and calculated values after the 1mm shim and the 2.99 mm gasket.

Table 3-V
1mm shim and 3mm gasket Measurement Values

Measurement	Value (mm)
T1	21.35
T2	17.97
A	7.82
B	19.99
C	23.93
D*	27.30
E	36.53
G	2.01
H	1.09

Adding the 1mm shim and the 2.99mm gasket brought the G and H values to near ideal values of G=2mm and H=1mm.

With the correct shims and gaskets in place, the gearbox was reassembled. The first stage cover was bolted on and the input shaft was spun by hand with no tight spots or issues. The electric motor and remaining hardware were reinstalled for testing. New oil was added to the gearbox, but did not show up on the sight glasses. The sight glasses were removed and replaced to verify oil level.

4. TESTING

The antenna was manually slewed back and forth for several minutes at 2/3 speed (default of manual mode). No abnormal noises were observed during this initial test.

The oil was drained again through paint filters to catch any particulates. The oil filter was also drained. A small amount of metallic particles were found in the oil filter, the paint strainers did not show any signs of metallic pieces, just brown sludge and gasket material.

New oil was added and the antenna was again manually slewed back and forth for several minutes. No abnormal noises were observed. The antenna was then handed over to operations to perform a pointing routine, in order to slew at full speed. The antenna ran for approximately 1 hour with no abnormal noises being observed. The antenna was then released back to the site techs to be put back into service.

5. FAILURE ANALYSIS

The first stage failure point showed that excessive pressure was applied to the first stage planetary gears. This is seen in the broken or flattened thrust washers. The two remaining thrust washers were flattened to approximately 0.85 mm or 0.15 mm smaller than the original 1.00 mm. Figure 5.1 and 5.2 detail the flattened thrust washers. Note that non-flattened portion was positioned under bearing.

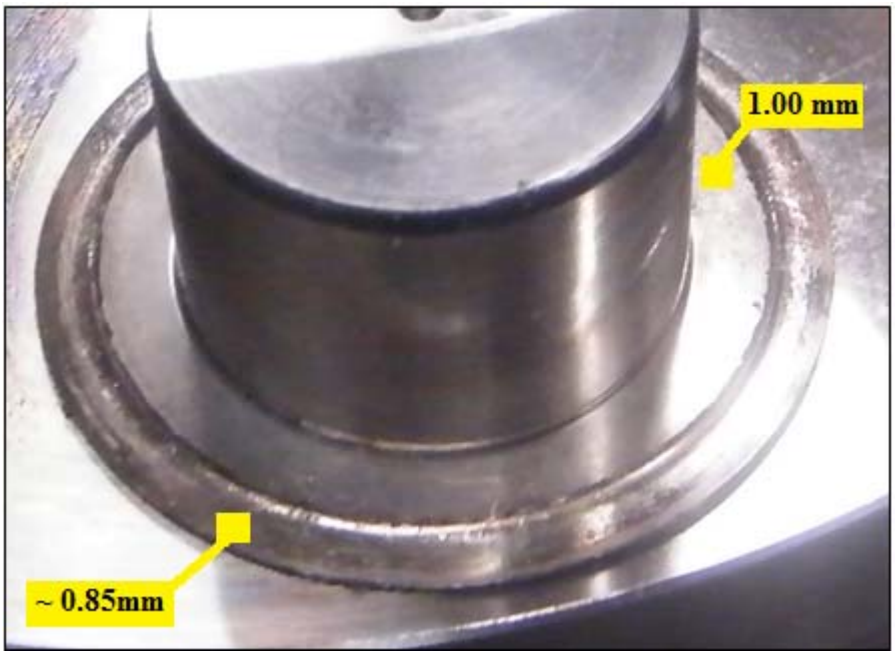


Figure 5.1: Flattened Thrust Washer Example

Figure 5.2: Broken and Flattened Thrust Washers

The wear marks can further be seen on the back side of the first stage planetary gears. All of the gears showed a groove where they were eating into the thrust bearings. Figure 5.3 details the gears and inside wear marks detailed by red arrows.

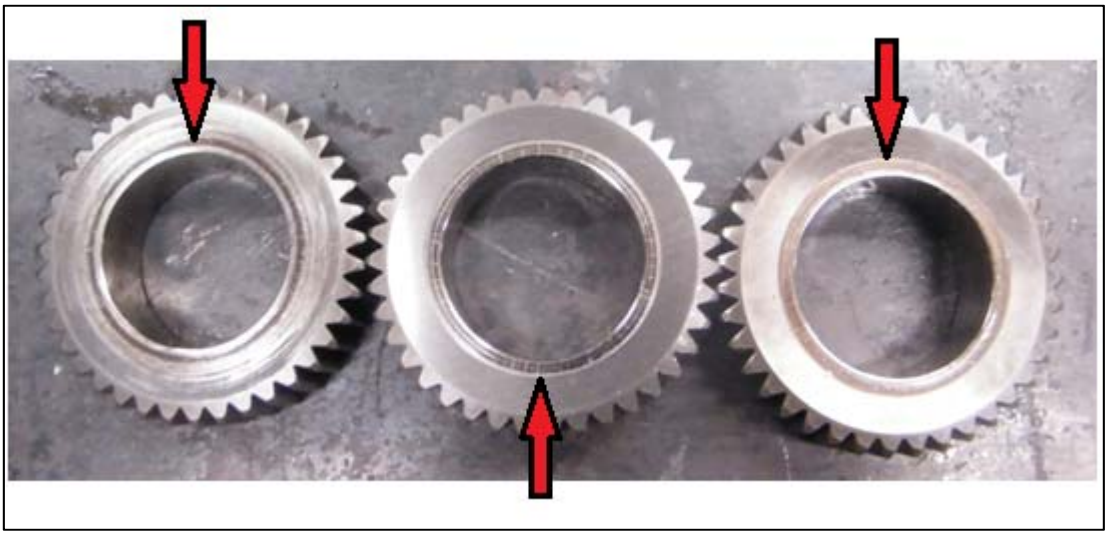


Figure 5.3: First Stage Gears w/ Wear Marks

In addition to the thrust washer failure, the planetary gear spindles also showed signs of excessive wear. The three spindles detail the outline of the thrust ring. Figure 5.4 and 5.5 detail the wear marks on the first stage spindles by the thrust ring.

Figure 5.4: First Stage Thrust Ring Wear Marks

Figure 5.5: First Stage Showing Thrust Ring

The thrust ring rides along the three first stage gears and sits in a grove on the front stage cover. Inspection of the front cover and thrust ring showed that the thrust ring appeared to be spinning within the case itself. The spinning caused both the ring and the case to be pitted and scored. The scarring on the front cover was deep enough that the spare cover was used for the repair. Figure 5.6 and 5.7 detail the wear on the back side of thrust ring and front cover.

Figure 5.6: Scored and Scratched Thrust Ring Grove.

Figure 5.7: Close up of Scored Thrust Ring

After returning to the VLA site, the first stage set was measured to determine the height difference between the gear spindle and the gear face. The height was taken using the "flattened" thrust washers. This height was compared to the first stage gear set in the spare gearbox. Figure 5.8 details the dimension and the height difference.

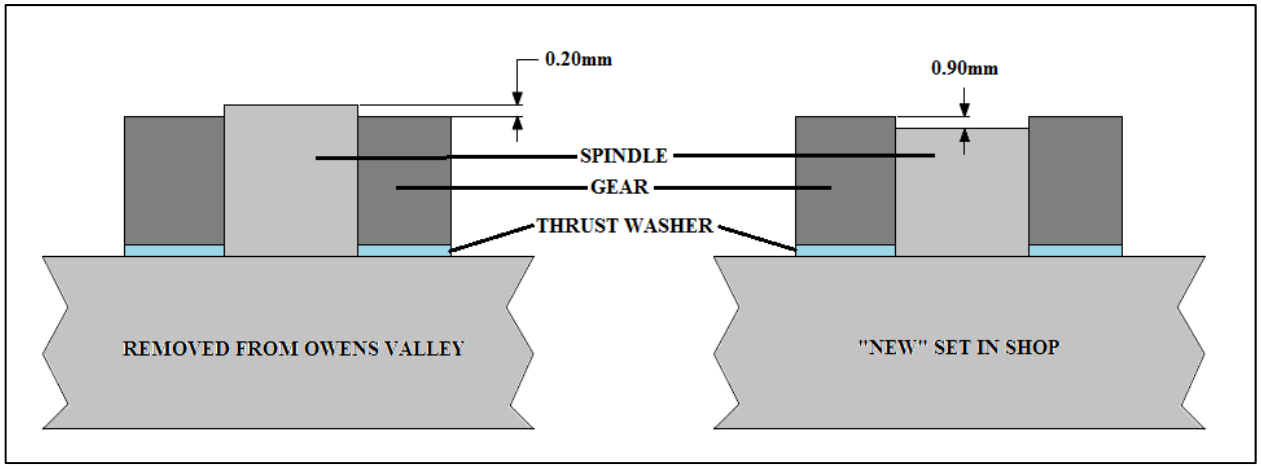


Figure 5.8: Gear to Spindle Height

The results show that the bearing on the "new" set of gears sits above the spindle, while the unit taken from Owens Valley sits below the spindle. Unfortunately, the first stage set of gears installed during this repair was not measured, nor was the original set that was removed (prior to installation).

CONCLUSION

If the Owens Valley first stage set of gears started life the same as the "new" set, the thrust ring would have pushed back the gears, not the spindles. Over time, the extensive pressure would flatten the thrust washers, allowing the gear to work its way down the spindle until the thrust ring was riding on the spindle itself, and not the gear. The thrust ring riding on the spindle over time most likely caused the ring to spin in the housing, causing it to become pitted and scratched. The noise observed by the site techs was most likely the culmination of metal to metal contact of the first stage planetary gears to thrust washers, thrust ring to gears, and thrust ring to housing.

During the 2002 visit to Owens Valley, the gearbox was also repaired. During final assembly it was determined that the gears were too long, approximately 0.020" or 0.50 mm. As with this rebuild, in 2002 gaskets were used to space the housing so the gears wouldn't have an interference fit.

Looking back at the procedure, it is essential that the value of G (distance between the thrust ring and gears) must be greater than H (distance between snap ring and input shaft). This ensures that the thrust bearing, behind first stage sun gear, engages or makes contact before the metal to metal contact of the thrust ring to gears. Figure 6.1 details the G and H dimensions again.

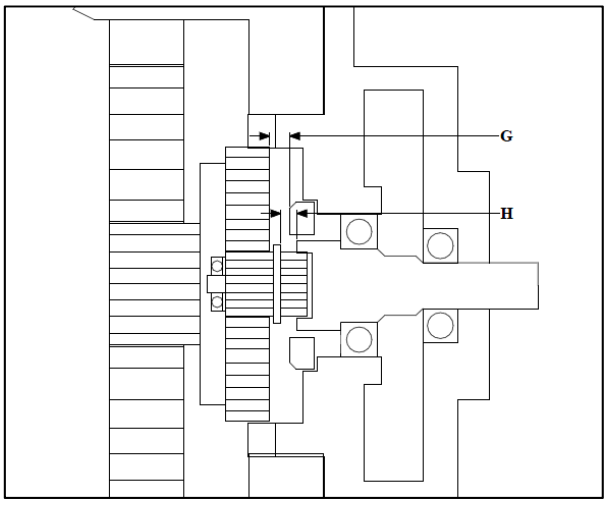


Figure 6.1: G and H Dimension Detail

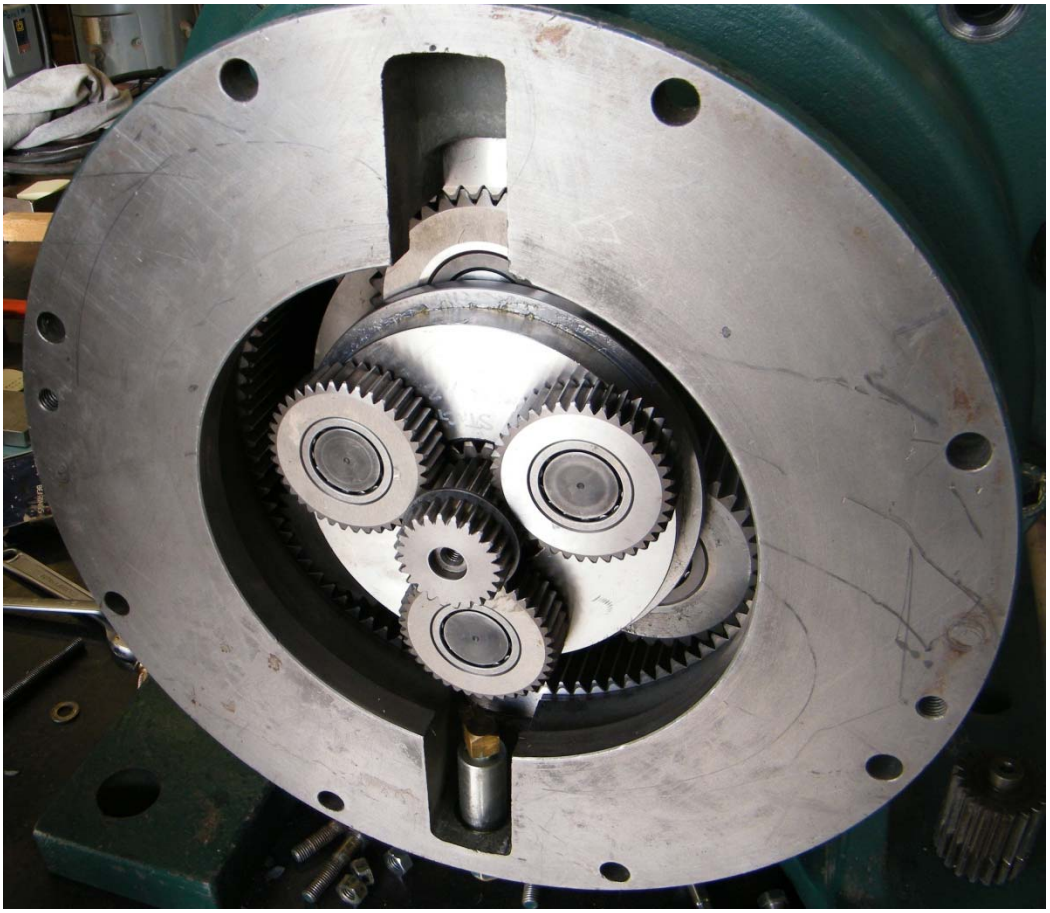
The most likely situation was that the cover was installed back in 2002 with G<H, over time the thrust ring pushed against the gears, causing the one of the thrust washer to fail. There was a small amount of damage to the first stage ring gear teeth, indicating that the washer probably fell into them. This may be the point where the sight techs started to hear the noise.

Appendix A:

VLBA COMPOWER GEARBOX AXIAL CLEARANCE ADJUSTMENT PROCEDURE MEASUREMENTS CALCULATION SHEET

VLBA COMPOWER GEARBOX AXIAL CLEARANCE ADJUSTMENT PROCEDURE
MEASUREMENTS CALCULATION SHEET

Instructions and Measurements Typical to all Gearboxes:



Prepared by
Michael Romero
12/3/14

1. Main Gearbox Side Tool Measurement

Before taking any measurements on either the main gearbox or the 1st stage input side, the measurement tool used on the main gearbox side is measured. Although the tool dimensions should not change, it is a good time to make sure the calipers are working correctly. Figure 1.1 details a cross sectional view of the main gearbox measurement tool and the two (2) dimensions to be measured. Record all measurements in Appendix A, Measurement Form.

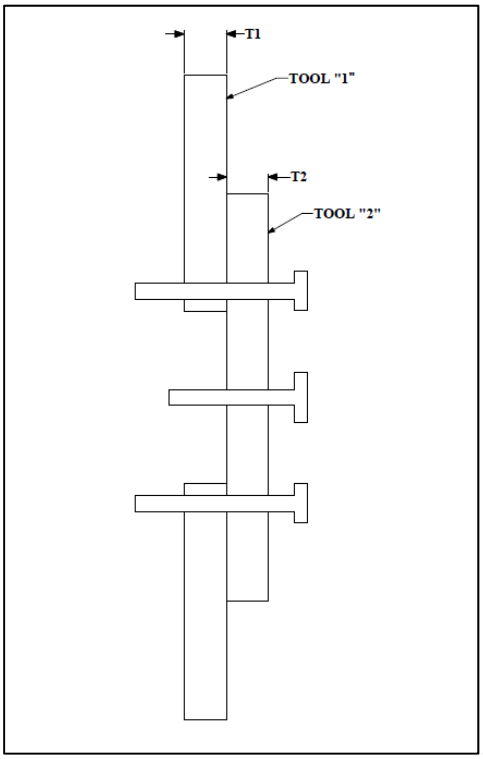


Figure 1.1: Main Gearbox Tool measurements.

T1=Flange thickness

Measure the thickness of the main flange. Ensure the tool is clean and free of foreign material and rust. A scotch pad may be used to clean the tool prior to measurement.

The value for T1 should be around ***21.35mm***.

T2=Sun gear hold down bar.

Measure the thickness of hold down bar. Ensure the tool is clean and free of foreign material and rust. A scotch pad may be used to clean the tool prior to measurement.

The value for T2 should be around ***18.00mm***.

2. First Stage Input Shaft Side

Measurement Setup:

Before taking measurements on the input shaft side, the input shaft must be seated and the first stage flange cleaned. Ensure all gasket material and silicone is removed from the first stage flange. Place the input shaft side assembly on a standoff in order to properly seat input shaft. Use a mallet or dead blow hammer to ensure input shaft is fully seated.

Note: Do not use metal hammer on input shaft to seat it. This may cause damage to the internal splines on the input shaft or the input shaft bearings. If no other options are available, a piece of wood between input shaft and hammer will work.

Figure 2.1 details a cross section of the input shaft side showing the proper setup for seating the input shaft.

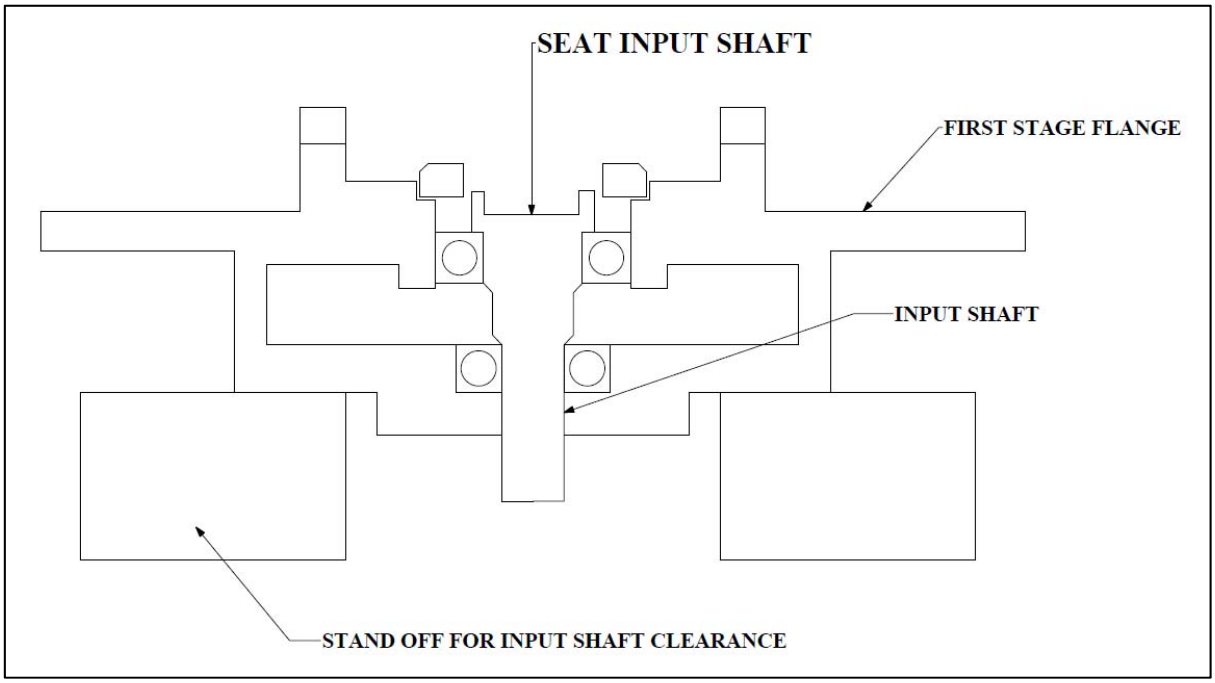


Figure 2.1: Input Shaft Side Setup.

Measurement Procedure:

Before taking any measurements, ensure the calipers are zeroed out and all surfaces are clean and free of any foreign material. Figure 2.2 details the three (3) measurements to be taken on the 1st stage input side. Record all measurements in Appendix A, Measurement Form.

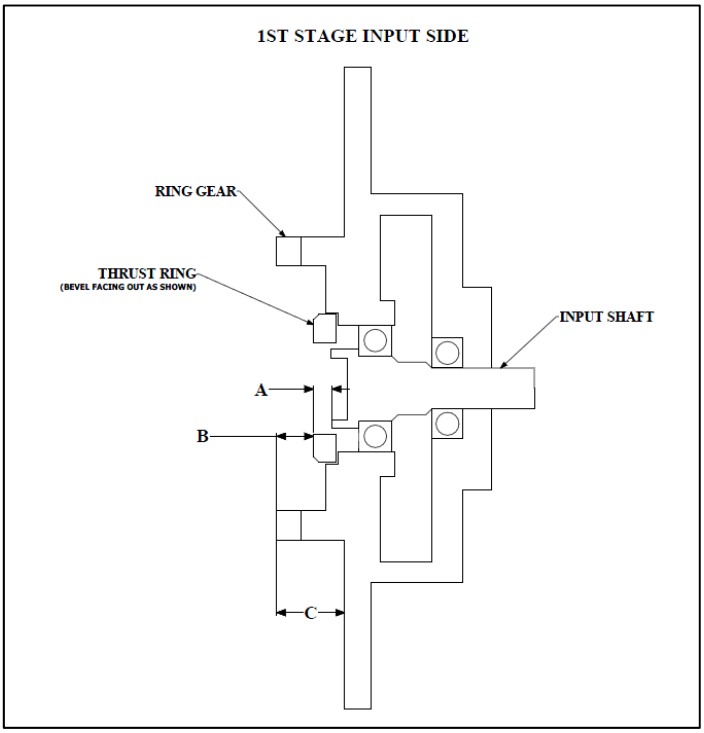


Figure 2.2: 1st Stage Input Side Measurements

A=Input shaft to thrust ring dimension.
Take this dimension from the top surface of the input shaft to the top surface of the thrust ring. Ensure the input shaft, thrust ring, and input side casing are clean and free of foreign material. Make sure the thrust ring has the bevel facing out as shown in Figure 2.2. **Note:** Pressure may have to be applied to thrust ring to make sure it is fully seated while taking measurement.

B=Thrust ring to ring gear dimension.
Take this dimension from the top surface of the thrust ring to the top surface of the first stage ring gear. Ensure the thrust ring and ring gear is clean and free of foreign material. **Note:** As with dimension A, pressure may have to be applied to thrust ring to make sure it is fully seated while taking measurement.

C=Thrust ring to flange dimension.
Take this dimension from the top surface of the thrust ring to the top surface of the first stage flange. Ensure the ring gear and flange is clean and free of foreign material.

3. Main Gearbox Side

Measurement Setup:

Before taking measurements on the main gearbox the measurement tool must be installed and the gear spacing adjusted.

Install the main gearbox measuremt tool as shown below in figure 3.1 and follow prodedures 1-9 below.

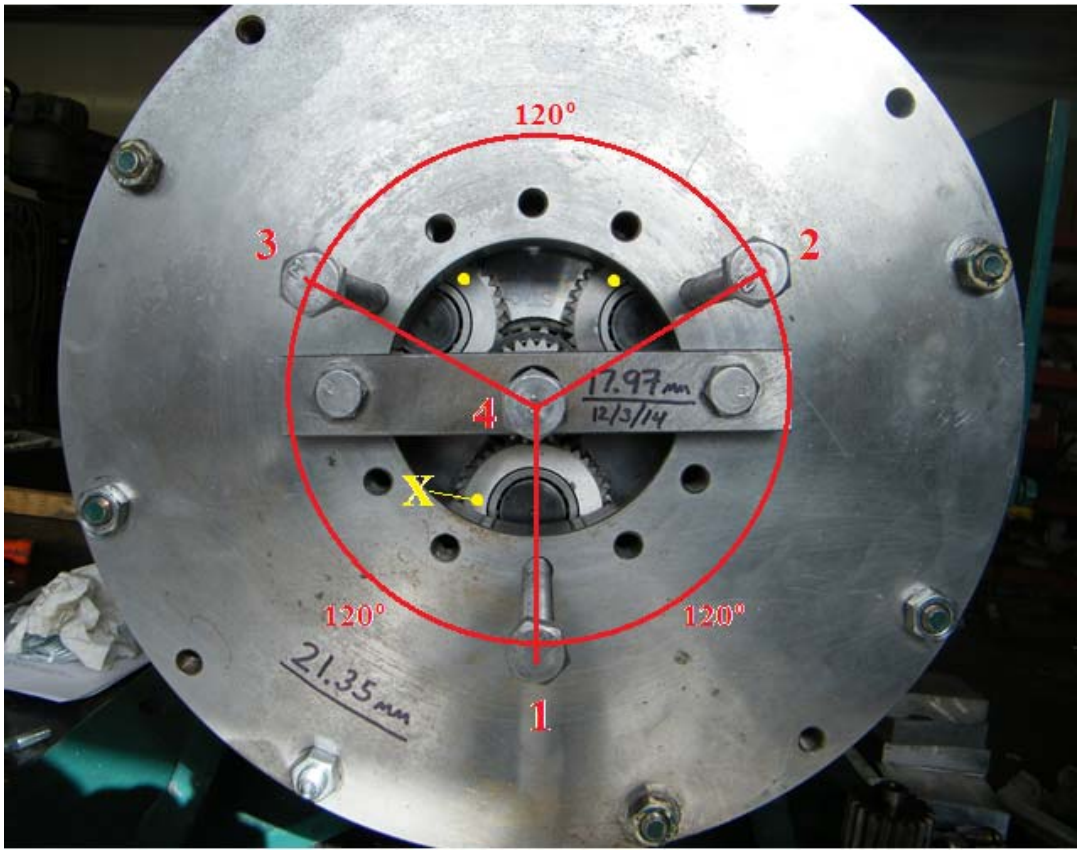


Figure 3.1: Main Gearbox Tool Setup:

1. Install the tool so that TOOL "2" (shown in Figure 1.1) is horizontal, as shown above. Ensure the flanges on both the tool and the gearbox are clean and free of contaminatnets before installing. Tighten the eight (8) bolts in a star pattern, making sure the flanges are flush and that there is no gap between the tool and the gearbox flange.

2. Install the three (3) outer lash bolts and center lash bolt as outlined in figure 3.1. Ensure that bolts (#1-3) are evently spaced as shown. Rotate the plantary gears so one gear is facing straight down, aligned with bolt 1 in figure 3.1.

3. Hand tighten the center lash bolt (#4). Once hand tight, turn the center bolt an additional 1/8 turn to set thrust bearing. Ensure the planitary gears are still in alightment.

4. **Hand tighten** the three (3) outer lash bolts, ensuring they are being tightened on the gear itself, not the center spindle. Try to make sure all the bolts are tightened the same. **DO NOT USE WRENCH.**

5. Before taking any measurements, ensure the calipers are zeroed out and all surfaces are clean and free of any foreign material. Using Figure 3.2, measure "D TEST" for the bottom gear (#1) at location X shown in Figure 3.1. Record this dimension in Appendex A; Measurment Form. Ensure measurmet X is taken as close to the edge of "TOOL 1" as possible

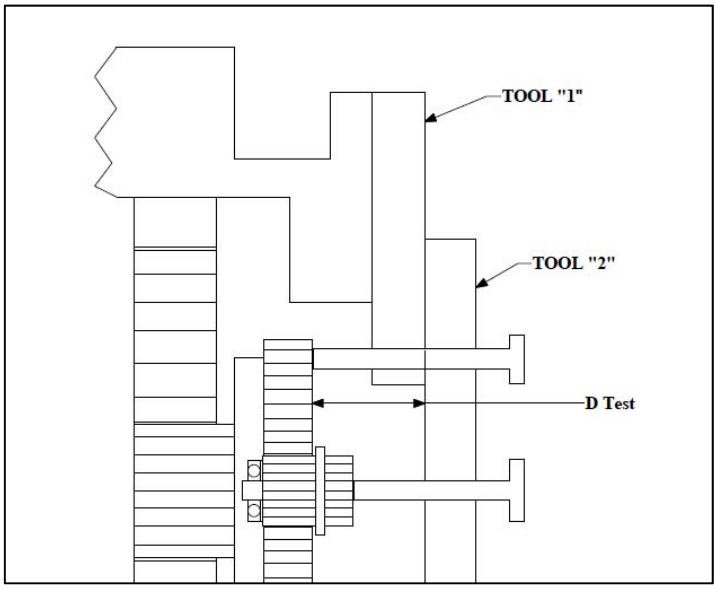


Figure 3.2: "D TEST" Measurment

"D TEST"= TOOL "1" flange to face of planitary gear.

6. Repeat step 5 for gears 2 and 3, taking measuremnts from the locations marked by yellow spots in figure 3.1 and record in Appendex A, Measurmetn Form.

7. Using "D Test" measurment table, calculate the range by subtracting the smallest value from the largest value. If the range is greater than 0.05mm, the gears have to be adjusted. If range is less than 0.05mm move on to measurement procedure.

8. Determine which of the three "D Test" measurments is the largest (farthest distance from TOOL 1).

9. Tighten the two other lash bolts approxamatly 1/8 of a turn (45 degrees). Repeate steps 5-7.

The following is an example of the steps detailed above.

Example:

Following Steps 1-7, the table below was filled out.

"D Test" Measurment	Value 1	Value 2	Value 3
1	30.25		
2	30.02		
3	30.05		
Range=Max-Min	0.23		

The table shows that "D Test" 1 was the largest value. Tighten lash bolts 2 and 3 1/8 turn and repeate steps 4-7

"D Test" Measurment	Value 1	Value 2	Value 3
1	30.25	30.23	
2	30.02	30.18	
3	30.05	30.16	
Range=Max-Min	0.23	0.07	

According to the table, the maximum range is 0.07mm, which is still greater than 0.05. Tighten lash bolts 2 and 3 slightly (1/8 a turn or less) and repete steps 4-7.

"D Test" Measurment	Value 1	Value 2	Value 3
1	30.25	30.23	30.24
2	30.02	30.18	30.20
3	30.05	30.16	30.21
Range=Max-Min	0.23	0.07	0.04

According to the table, the maximum range is 0.05mm, or less than 0.05mm and acceptable.

If range is still too large after the second adjustment (value 3). Loosen lash bolts and go back to step 2 and repeate procedure.

Measurement Procedure:

Before taking any measurements, ensure the calipers are zeroed out and all surfaces are clean and free of any foreign material. Figure 3.3 details the two (2) measurements to be taken on the main gearbox. Record all measurements in Appendix A, Measurement Form.

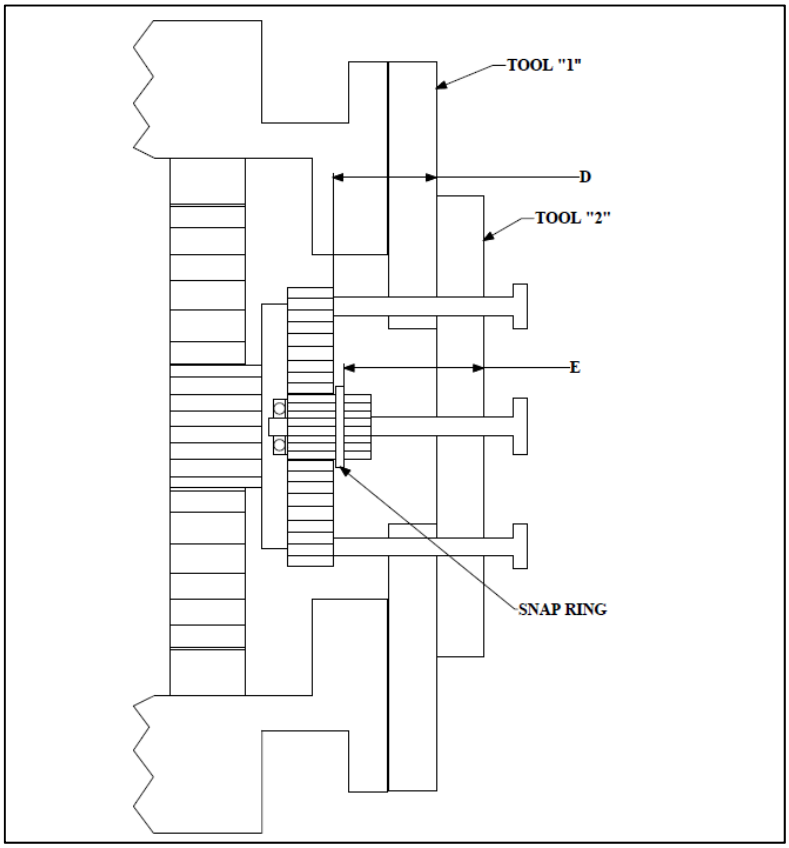


Figure 3.3: Main Gearbox Measurements

D= TOOL "1" flange to face of planitary gear.

Take this dimension only after completing the measurement setup procedure. Take this measurement from the bottom gear (1) at detailed in Figure 3.1. Ensure all surfaces are clean and free of foreign material.

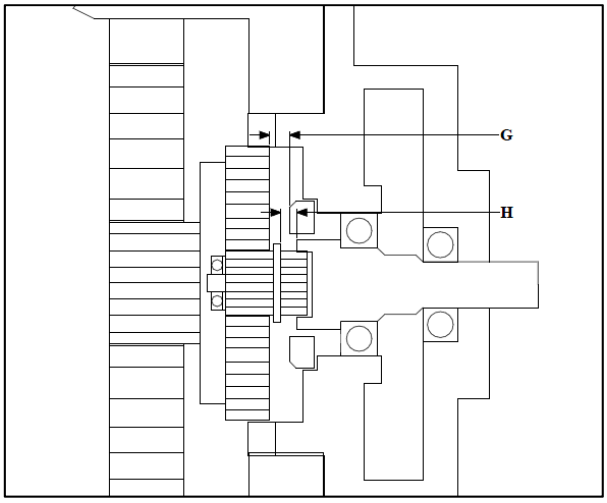
E=Snap ring to TOOL "2" face.

Take this dimension from the top surface of TOOL "2" to the snap ring on the sun gear. Ensure all surfaces are clean and free of foreign material.

4. Calculations:

The following text details the dimensions calculated, refer to Appendix B, Calculation Form, for actual calculation work.

Figure 3.4 details the calculated G and H distance.



G=Distance from thrust ring to face of planetary gears. This gap can vary and range up to 2mm.

$$G = D - T1 - C + B$$

H=Distance from snap ring to input shaft surface. This is typically 1mm.

$$H = E - T2 - T1 - C + A + B$$

Dimension G should be greater than H (G>H). If G<H, the ring gear will come in contact with the planetary gears before the thrust bearing located behind the sun gear.

Assuming G>H and if:

H value is larger than 1mm (H>1mm), shims can be used to bring H closer to 1mm.

S=Suggested shim thickness

H-S=1mm

S=1mm+H

H value is smaller than 1mm or negative (H<1mm), the 1st stage has to be shimmed from the main gearbox flange. This can be done by using 1/16" or 1/32" gasket material (1"= 25.4mm)

K=Suggested gasket thickness

H+K=1mm

K=1mm-H

G must be greater than H to prevent metal on metal contact. If G is less than H, the following suggested shim thickness can be used.

S1=Suggested shim thickness (if G<H)

(H-G)+S1=1mm

S1=1-(H-G)

Appendix A
Measurement Form

Tool Values:

T1=_____

T2=_____

First Stage Values:

A=_____

B=_____

C=_____

Main Gearbox Tool Test Values:

"D Test" Measurment	Value 1	Value 2	Value 3
Gear 1			
Gear 2			
Gear 3			
Range=Max-Min*			

*Range must be less than 0.05mm

Main Gearbox Values:

Value 1	Value 2	Value 3
	Shim Size=_____	**Shim Size=_____**
D=_____	**D=_____**	**D=_____**
E=_____	**E=_____**	**E=_____**

Appendix B
Calculation Form

Calculating G and H

$$G = D - T1 - C + B$$
$$H = E - T2 - T1 - C + A + B$$

G and H Values:

Suggested Value	Value 1	Value 2	Value 3
		Shim Size=_____	Shim Size=_____
G=_2mm___	G=_____	G=_____	G=_____
H=_1mm___	H=_____	H=_____	H=_____
G-H=_1mm___	G-H=_____	G-H=_____	G-H=_____

FOR G<H

H>1mm $Suggested\ Shim\ Size = S = H + 1mm$			H<1mm $Suggested\ Gasket\ Size = K = 1mm - H$		
Value 1	**Value 2**	**Value 3**	**Value 1**	**Value 2**	**Value 3**
	Shim Size=___	Shim Size=___		Gasket =____	Gasket =____
S=_____	S=_____	S=_____	K=_____	K=_____	K=_____

FOR G>H

H>1mm $Suggested\ Shim\ Size = S1 = G - H + 1mm$		
Value 1	**Value 2**	**Value 3**
	Shim Size=___	Shim Size=___
S=_____	S=_____	S=_____

Appendix C

Original Calculation Cross Reference

Figure C.1 details the original schematic used for measurement. Use figures located in document to reference dimensions below.

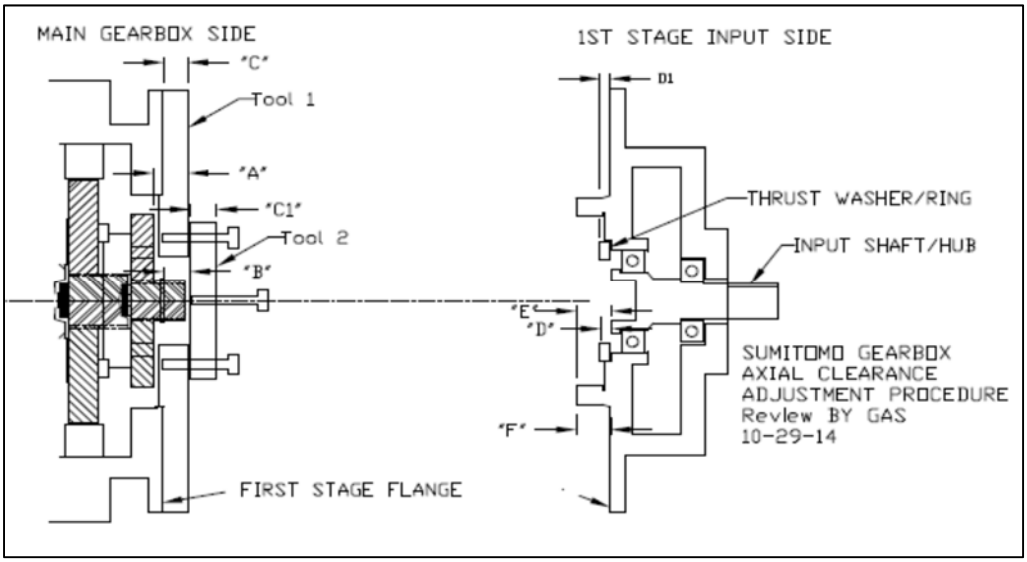


Figure C.1: Original Schematic

Original Schematic Dimensions	Document Schematic Dimensions
A	D
B	E-T2
C	T1
C1	T2
D	A
E	A+B
F	C
D1	D1’
G1	G
X	H

Original Formula	Modified Formula
D1=D-E+F	D1’=A-(A+B)+C D1’= -B+C D1’= C-B
G1=A-C-D1	G=D-T1-D1’ G=D-T1-C+B
X=B-C-F+E	H=(E-T2)-T1-C+(A+B) H=E-T1-T2-C+A+B