☐ ANO-1	☐ ANO-2	☐ GGNS	☐ IP-2	☐ IP-3	☒ PLP
☐ JAF	☐ PNPS	☐ RBS	☐ VY	☐ W3	
☐ NP-GGNS-3	☐ NP-RBS-3				

CALCULATION COVER PAGE	(1) **EC # 31177**	(2) **Page 1 of 34**
(3) Design Basis Calc. ☐ YES ☒ NO	(4) ☒ CALCULATION ☐ EC Markup	
(5) **Calculation No: EA-EC31177-01**		(6) **Revision: 0**
(7) **Title: Calculation of Overspeed Trip Mechanism Linkage Forces**		(8) **Editorial** ☐ YES ☒ NO
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MPR Associates / 11-30-11	SG Kopke / [signature] 11-30-11	T Fouty / [signature] 11/30/11
Responsible Engineer	☐ **Design Verifier** ☒ **Reviewer** ☐ Comments Attached	**Supervisor/Approval** ☐ Comments Attached

Revision	Record of Revision
0	Initial issue.

CALCULATION REFERENCE SHEET	CALCULATION NO: EA-EC31177-01 REVISION: 0

I. EC Markups Incorporated (N/A to NP calculations)

1. N/A
2.
3.
4.
5.

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1. N/A	--	--	☐	☐	--	--
2.			☐	☐		
3.			☐	☐		
4.			☐	☐		
5.			☐	☐		

III. CROSS REFERENCES:

1. Palisades Condition Report CR-PLP-2011-02350 "Auxiliary Feedwater Pump P-8B Tripped on Overspeed"
2. Elliott Turbomachinery Technical Manual 100M for Elliott DYRT Turbine, B902105MOD.1
3. Machinery Handbook, Oberg, Jones, Horton and Ryffel, 25th ed. Industrial Press 1996
4.
5.

IV. SOFTWARE USED:

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V. DISK/CDS INCLUDED:

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VI. OTHER CHANGES:

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VENDOR DOCUMENT REVIEW STATUS

☒ FOR ACCEPTANCE ☐ FOR INFORMATION

☐ IPEC ☐ JAF ☒ PLP ☐ PNPS ☐ VY ☐ ANO ☐ GGNS ☐ RBS ☐ W3 ☐ NP

Document No.: 0098-1103-0171-00	Rev. No.4
Document Title: Calculation of Overspeed Trip Mechanisim Linkage Forces	
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Acceptance does not constitute approval of design details, calculations, analyses, test methods, or materials developed or selected by the supplier and does not relieve the supplier from full compliance with contractual negotiations.

Responsible Engineer SGKupka / [signature] 11-30-11
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Print Name / Signature / Date

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CALCULATION TITLE PAGE

Client: Palisades Nuclear Plant	Page 1 of 30
Project: Overspeed Trip Mechanism Evaluation	Task No. 0098-1103-0171-00
Title: Calculation of Overspeed Trip Mechanism Linkage Forces	Calculation No. 0098-0171-01

Preparer / Date	Checker / Date	Reviewer & Approver / Date	Rev. No.
Patrick Butler August 5, 2011	Amber Su August 9, 2011	Ben Frazier August 9, 2011	0
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RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page: 2
0098-0171-01	*(signature)*	*(signature)*	

Revision	Affected Pages	Description
0	All	Initial Issue
1	All	Added a summary of the critical variable calculations to Section 2.0. This change is indicated by a revision bar. Revision note was removed from the body of the calculation.
2	All	Changed the modeling of the linkage to specifically address mass of the Resetting Lever, force from Backseat Spring on Resetting Lever, moment of torsional spring on Hand Trip Lever. Revised the model of the Hand Trip Lever to include the complete lever. Used vibration data during turbine operation taken at the end of the Resetting Lever instead of older vibration data from the Governor Added a modal analysis of the linkage to determine the natural frequencies, mode shapes and modal participation of modes near frequencies where vibration peak accelerations were measured.
3	All	Changes made to incorporate Energy comments as follows: • Discussion of Knife Edge/Latch contact area added • Assumption regarding horizontal acceleration added • Added clarification regarding iterative process used in calculation • Change in location of measured force associated with torsional spring • Additional clarifications and corrections.
4	All	Revised Figures 3-4, 3-5 and 3-9 to be more readable. Eliminated redundant page 19.

Table of Contents

1.0 PURPOSE

During a routine plant surveillance test of Auxiliary Feedwater Pump P-8B, the turbine overspeed trip mechanism actuated resulting in a trip of the feed pump. As documented in Entergy Condition Report CR-PLP-2011-02350 (Reference 1), the pump was declared inoperable. Investigations determined that during recent maintenance of the turbine, lubricant was applied to the mating knife edge surfaces of the trip linkage. These surfaces are not intended to be lubricated. This calculation determines the applied forces and resulting moments on the trip linkage components. In addition, this calculation determines if addition of the lubricant to the knife edge sufficiently reduces friction at the knife edge such that a trip would be expected at Resetting Lever vibration levels measured during normal operation of the pump.

2.0 SUMMARY OF RESULTS

The results of this calculation show that the given typical coefficient of friction values of 0.8 associated with dry conditions, 0.16 associated with lubricated conditions and a coefficient of friction of zero, the geometry of the linkage is such that the following combined vertical and horizontal accelerations are needed to overcome the friction and trip the linkage.

Coefficient of Friction	Required Combined Vertical and Horizontal Acceleration required to Trip Linkage
0.8	36.14 g left and 36.14 g upward
0.16	36.4 g left and 36.4 g upward
0	1.85 g left and 1.85 g downward

Measured values of horizontal and vertical acceleration and displacement of the Resetting Lever near the knife edge during operation of the pump are as follows:

Acceleration Direction	Peak Acceleration Over Complete Frequency Range (g)	Peak Spectral Acceleration Value (g)	Frequency at Peak Spectral Acceleration (Hz)	Total Displacement (in)
Horizontal (perpendicular to Resetting Lever Axis)	2.77	.85	1400	0.0068
Vertical	8.11	3.39	2200	0.0052

The measured values of acceleration are below those expected to cause trip of the linkage under lubricated conditions. Further, the frequencies at which the measured peak accelerations occur are sufficiently high that resulting displacements are significantly below the displacements required to trip the linkage.

Finally, modal analysis of the trip linkage showed that fundamental frequencies of the Hand Trip Lever and the Resetting Lever start at 230 Hz and that the 9th and 11th fundamental frequencies at 1489 Hz and 2023 Hz, respectively are close to the measured frequencies of 1400Hz and 2200Hz. The mass participation of each of these modes is a generally small (on the order of 2 to 8 percent) although in the Z direction, mass participation is approximately 30%. However, the high frequency of these modes does not result in significant response of the linkage. The mass participation of each of these modes is a small percentage of the overall mass (i.e., less than 0.2%) and these modes are not expected to result in significant response of the linkage.

In summary, the geometry of the linkage is such that large accelerations are needed to cause it to trip, the actual measured accelerations are small relative to those required to cause trip and the measured displacements on the order of 0.007 inches are too small to move the Hand Trip Lever the approximate 0.125" (Reference 2, page 4-15) required to cause it to trip.

3.0 DISCUSSION

The AFW pump turbine overspeed trip mechanism is illustrated in Figure 3-1. As shown in the figure, the end of the pump turbine shaft includes a spring loaded Overspeed Trip Pin Assembly inside of it. If the rotational speed exceeds a specified value, the pin will extend from the shaft, strike the Plunger Assembly and will cause the Hand Trip Lever to rotate counter-clockwise. The

Knife Edge of the Resetting Lever will disengage from the Latch of the Hand Trip Lever and the Closing Springs will rotate the Resetting Lever counter-clockwise. The Trip Valve will close, steam supply to the turbine will be cut off, and the turbine will stop.

To allow calculation of the forces acting on the various components of the Overspeed Trip Mechanism (OTM), a walkdown was performed and dimensions of the components were obtained. The dimensions taken for the Hand Trip Lever and Resetting Lever are shown in Figures 3-2 and 3-3, respectively. The dimensions for the Hand Trip Lever and Resetting Lever were obtained during walkdowns of the Auxiliary Feedwater Pump performed on May 19, 2011 and October 25, 2011. Solid CAD models were made from the walkdown dimensions and the solid models were used to determine the locations of the centroids and the masses of both components. The locations of the centroids for the Hand Trip Lever and the Resetting Lever relative to their pivot points are provided in Figure 3-4.

The Solidworks solid modeling program was used to determine that the volume of material in the Hand Trip Lever is 11.07 cubic inches. Assuming that Hand Trip Lever is cast carbon steel with a density of 0.29 lbm/in^3, the mass of the Hand Trip Lever is 3.21 lbm. In addition, the Solidworks software was used to determine that the centroid of the Hand Trip Lever is 1.06 inches above its pivot in the vertical direction and is 0.82 inches to the left of its pivot point, as shown in Figure 3-4.

The dimensions for the Resetting Lever on Figure 3-3 were used to build a solid model of the Resetting Lever using the Solidworks CAD software. Solidworks was used to determine that the volume of material in the Resetting Lever is 22.43 cubic inches. Assuming that Resetting Lever is cast carbon steel with a density of 0.29 lbm/in^3, the mass of the Resetting Lever is 6.49 lbm. In addition, the Solidworks software was used to determine that the centroid of the Resetting Lever is 10.73 inches from the knife edge and is 0.52 inches below the centerline of the circular section of the arm, as shown in Figure 3-4. Note that as documented in Reference 6, weight and center of gravity measurements taken for the Resetting Lever by Palisades maintenance personnel were 6.56 lbm and 10 3/4 inches from the knife edge.

To allow calculation of the forces on the OTM and to assess the impact of addition of lubricant to the mating Knife Edge and Latch, free body diagrams for the Hand Trip Lever and Resetting Lever were prepared as shown in Figure 3-5.

As shown in the exploded view in Figure 3-7, there is a torsional spring (Item 32) that is installed on the Hand Trip Lever. The torsional spring applies a moment in the clockwise direction (as viewed in Figure 3-1) and prevents the Hand Trip Lever from disengaging from the Resetting Lever. Measurements were taken by Palisades maintenance personnel that indicated that with the Hand Trip Lever in its set position, a force of 3.65 lbf applied at the centerline of the Resetting Lever is needed to overcome the spring force.

While vibrations measurements are taken during surveillance testing of the AFW pump, the vibration instrumentation is attached to the governor housing and results obtained may not be representative of vibration of the OTM mechanism components. To address this, Palisades ran the AFW pump with vibration instrumentation attached directly to the Resetting Lever near the Knife Edge as shown in Figure 3-6. Tests were run with the pump in recirculation mode as well as when providing flow to the steam generators. Since the vibration data taken while the pump was in recirculation mode is greater, it will be used in this calculation and is provided for the vertical and horizontal directions in Figure 3-8. The measurement data is from Reference 7.

To address concerns over lateral motion of the Resetting Lever, the lateral motion will be evaluated. Free body diagrams for the Resetting Lever for lateral motion was prepared as shown in Figure 3-9.

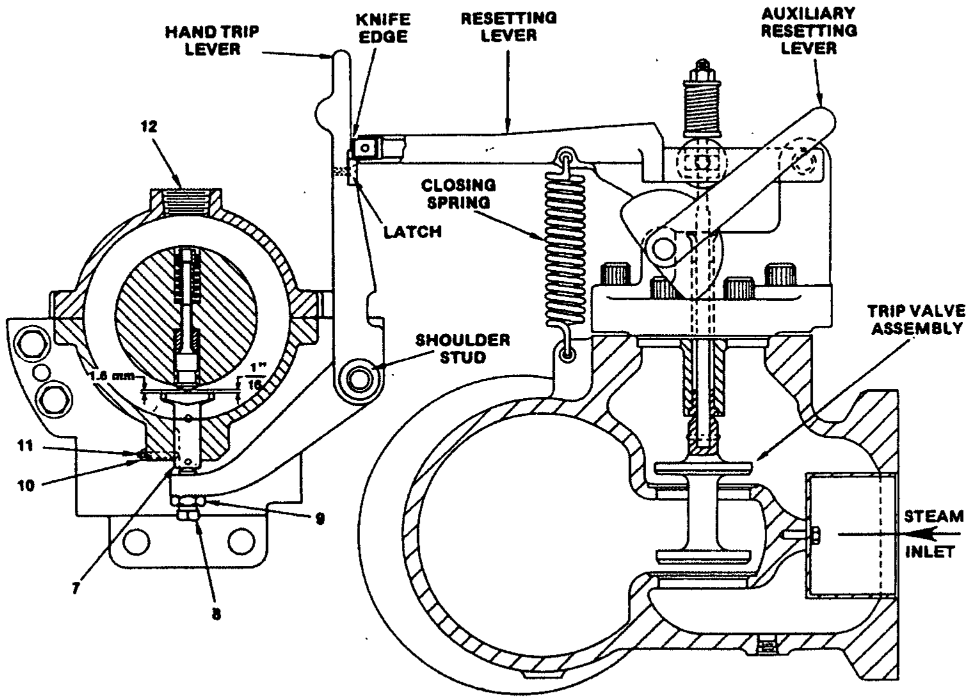
4.0 ASSUMPTIONS

1. The measured accelerations are assumed to be sinusoidal. This allows use of a factor of 1.414 to convert root-mean-square acceleration to peak acceleration. This is a reasonable assumption and introduces no bias into the calculation.

2. Accelerations measured when the pump was operated in recirculation mode bound accelerations measured when the pump was operated with flow to the steam generator as existed during the spurious trip.

3. The material for the Resetting Lever and the Hand Trip Lever is assumed to be cast carbon steel. This assumption introduces no bias into the calculation because the material is clearly metallic and will have a density close to the 0.29 lb/in^3 value assumed. If this assumption is determined to be in error, the impact on the material density will be small and is not expected to change the results of the calculation.

4. The calculation that determines the vertical acceleration and the horizontal acceleration in the direction of the Resetting Lever necessary to overcome various coefficients of friction assumed that the magnitudes of the horizontal and vertical accelerations were equivalent. The intent of the calculation is to provide an estimate of the acceleration value needed to cause the linkage to trip and as such is reasonable. Further, the measured value of acceleration in the vertical direction was significantly larger than the acceleration in the horizontal direction perpendicular to the Resetting Lever and is expected to also be larger than the acceleration in the horizontal direction parallel to the Resetting Lever, which was not measured.



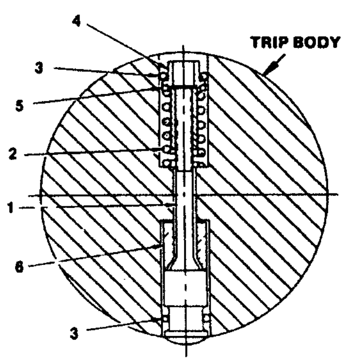


FIGURE ITEM NUMBER	DESCRIPTION	QUANTITY
4-7-1	*TRIP PIN*	*1*
2	*TRIP SPRING*	*1*
3	*"U" LOCK STAPLE*	*2*
4	*ADJUSTING NUT*	*1*
5	*WASHER*	*
6	AUXILIARY WEIGHT	1 *
7	*PLUNGER ASSEMBLY*	*1*
8	JACKSCREW	1
9	JAM NUT	1
10	JAM NUT	1
11	SET SCREW	1
12	INSPECTION PLUG	1

* Indicates part not used on all turbines or variable quantities.

Figure 3-1. AFW Pump Turbine Overspeed Trip Mechanism

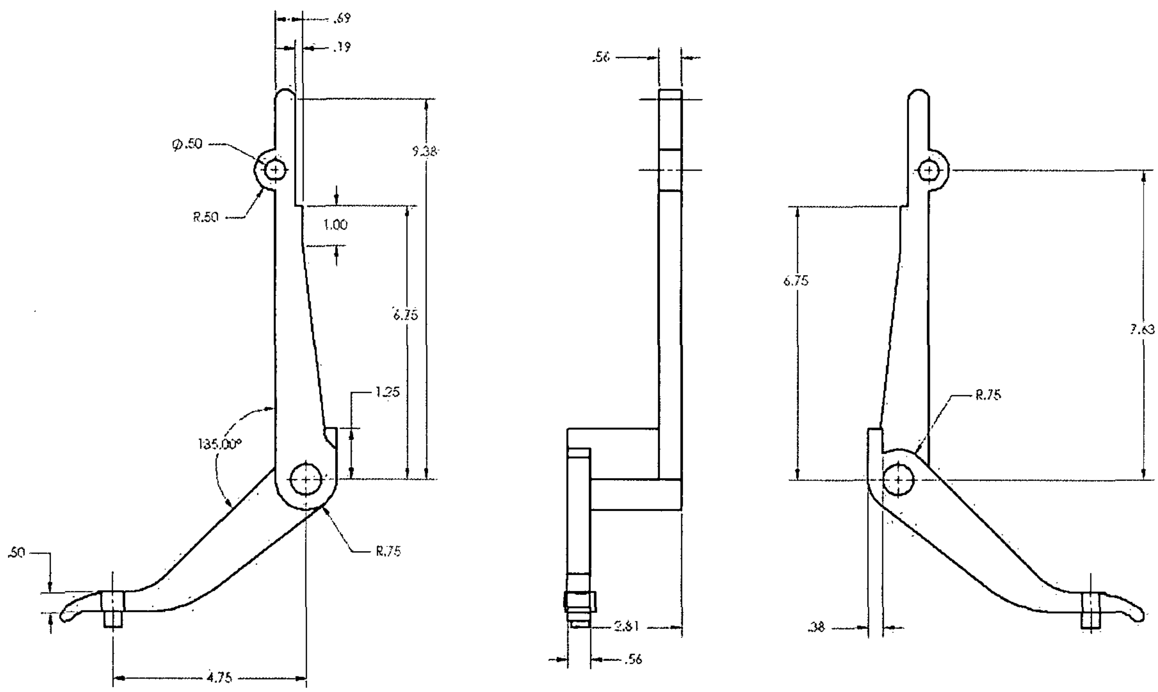


Figure 3-2. Dimensions of Hand Trip Lever

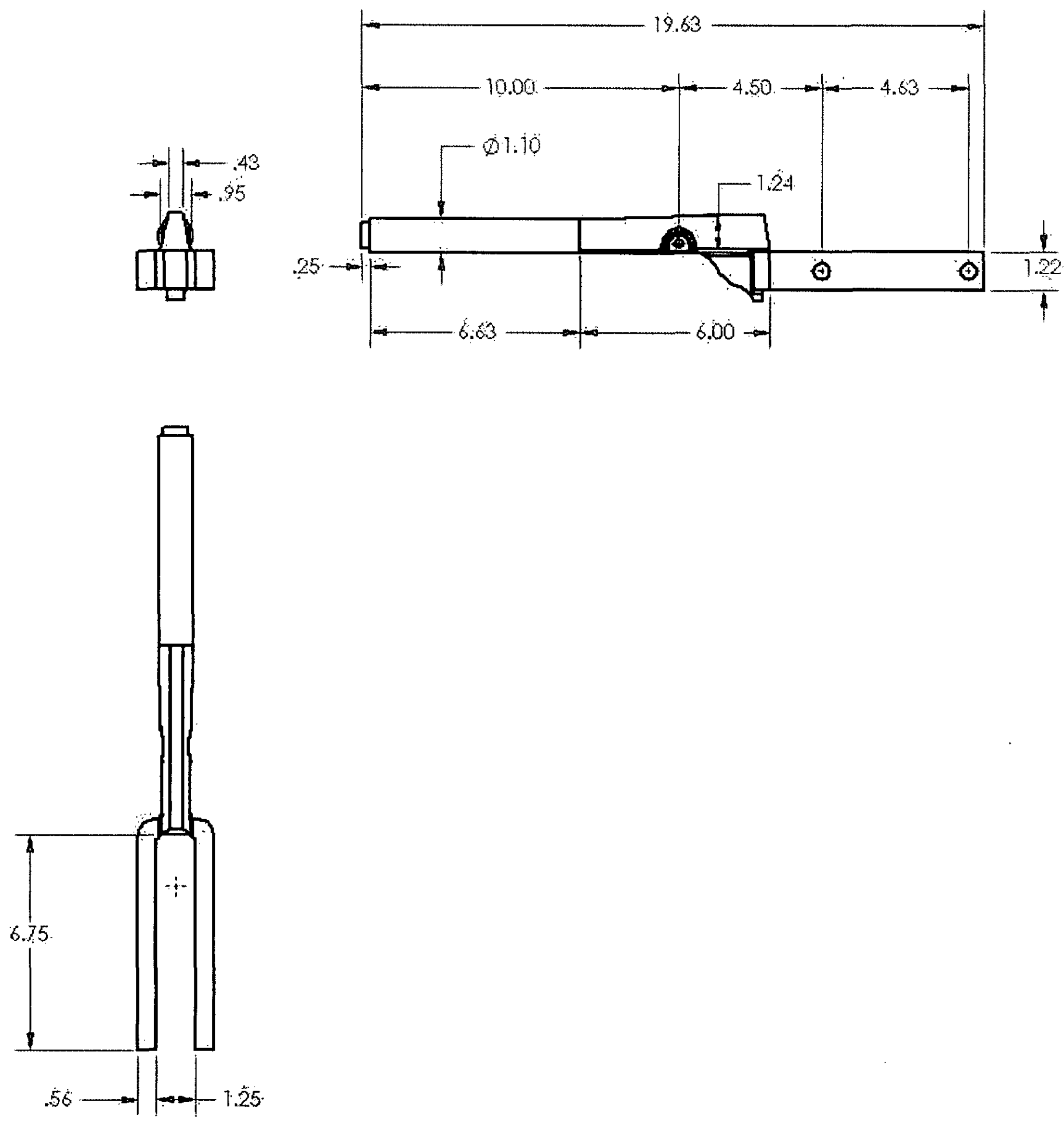


Figure 3-3 Dimensions of Resetting Lever

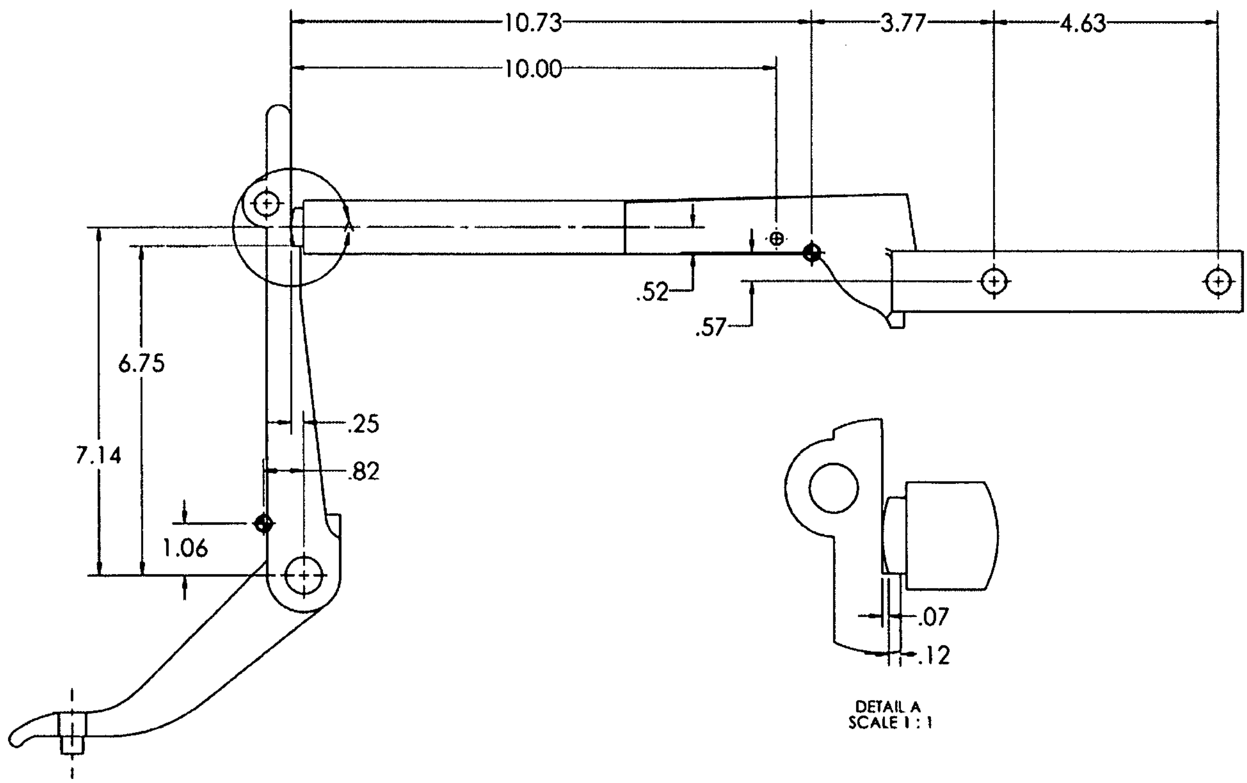


Figure 3-4. Overspeed Trip Mechanism - Resetting Lever & Hand Trip Lever Centroid Locations (Dimensions in Inches)

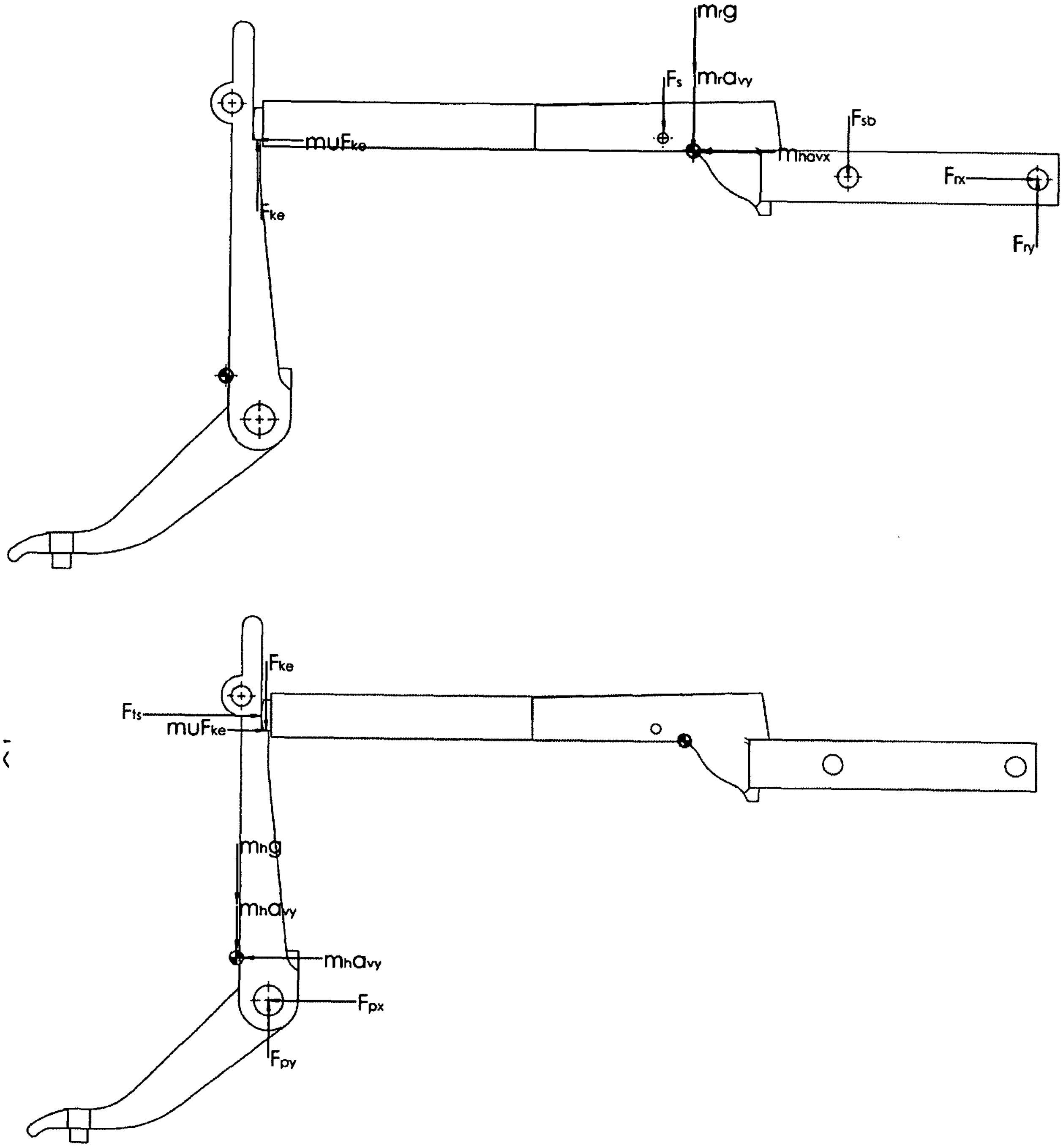


Figure 3-5. Free Body Diagrams for Resetting Lever and Hand Trip Lever

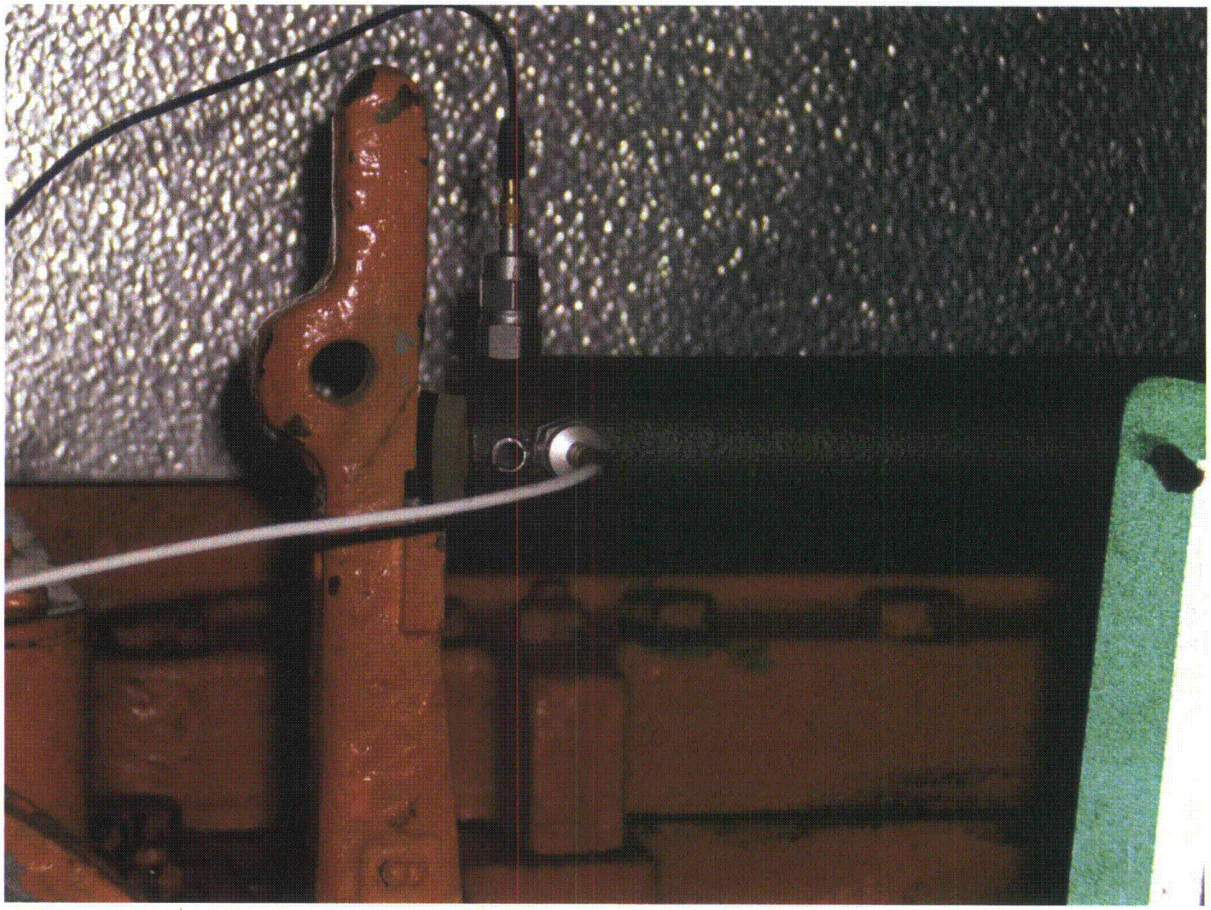


Figure 3-6 Locations of Vibration Transducers on Resetting Lever

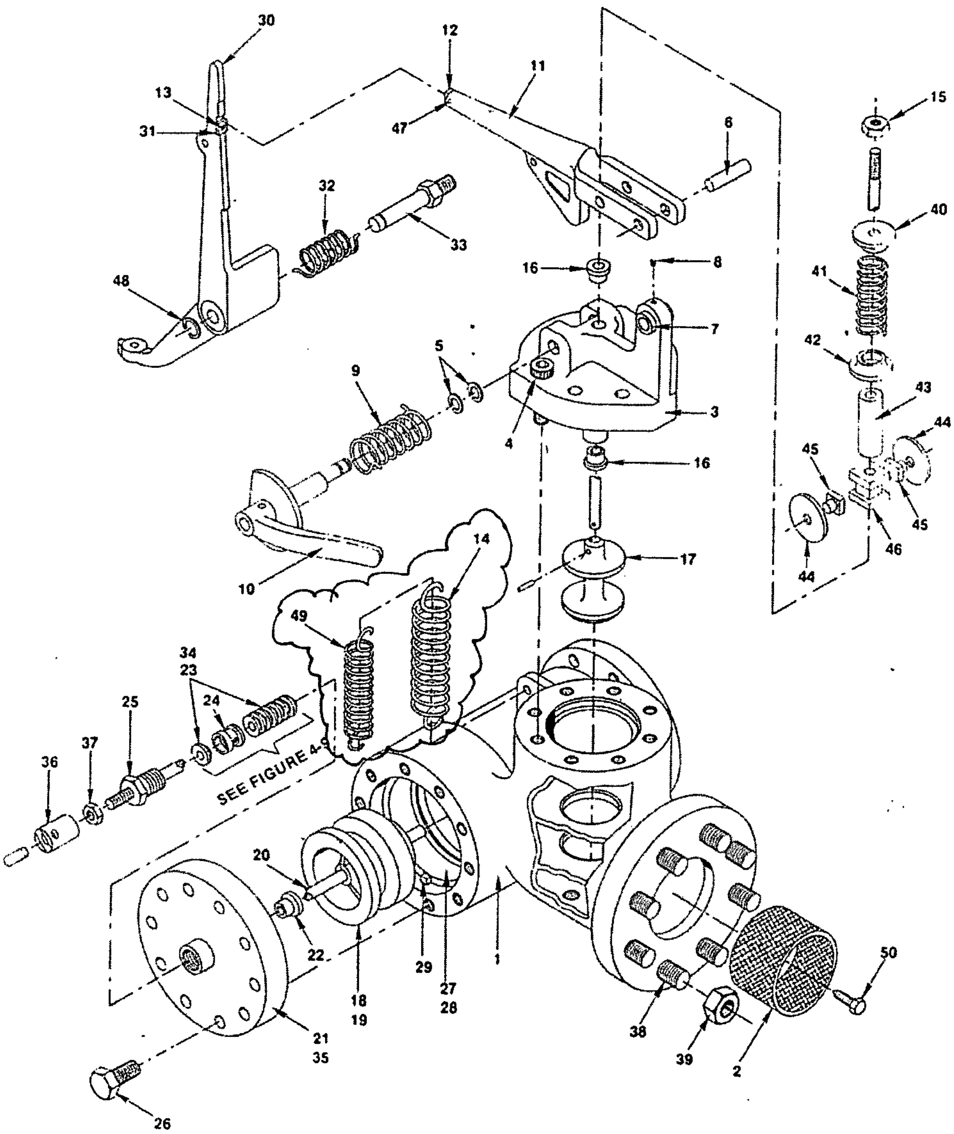


Figure 3-7 Exploded View Showing Torsional Spring on Hand Trip Lever (Item 32) (note - the Resetting Lever, Item 11, in the figure has a slightly different configuration than the actual component)

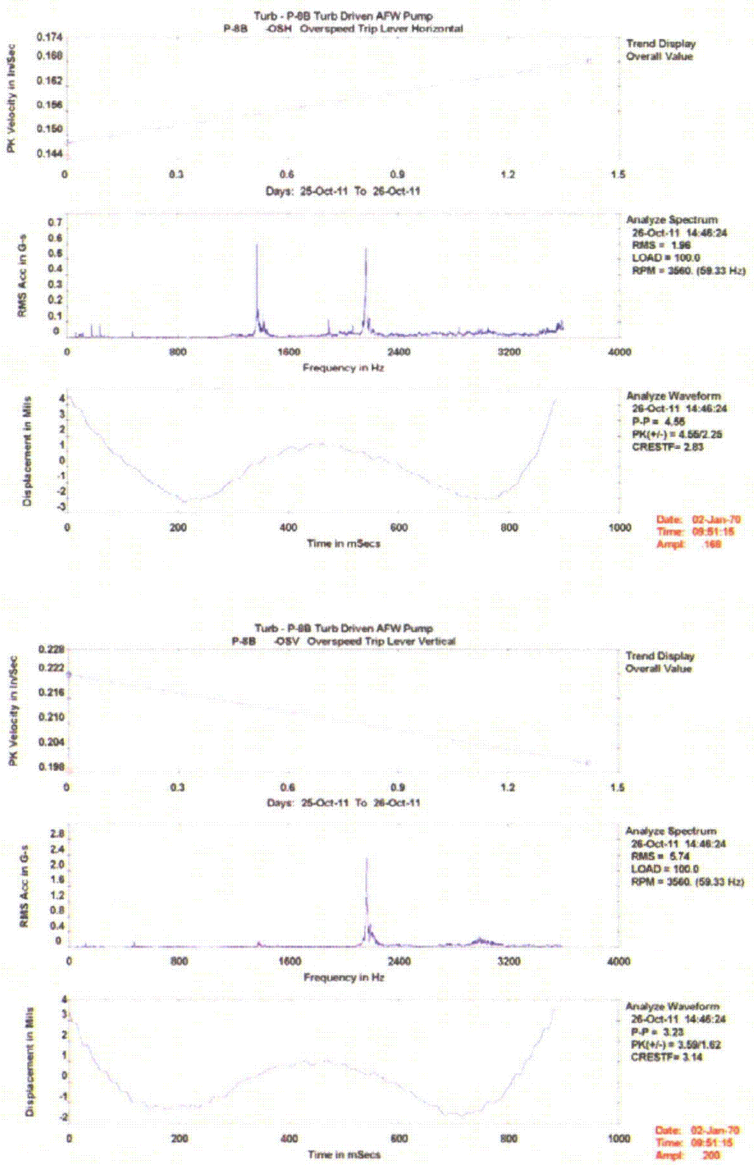


Figure 3-8 Recirculation Mode Vibration Measurements for Resetting Lever Near Knife Edge (Reference 7)

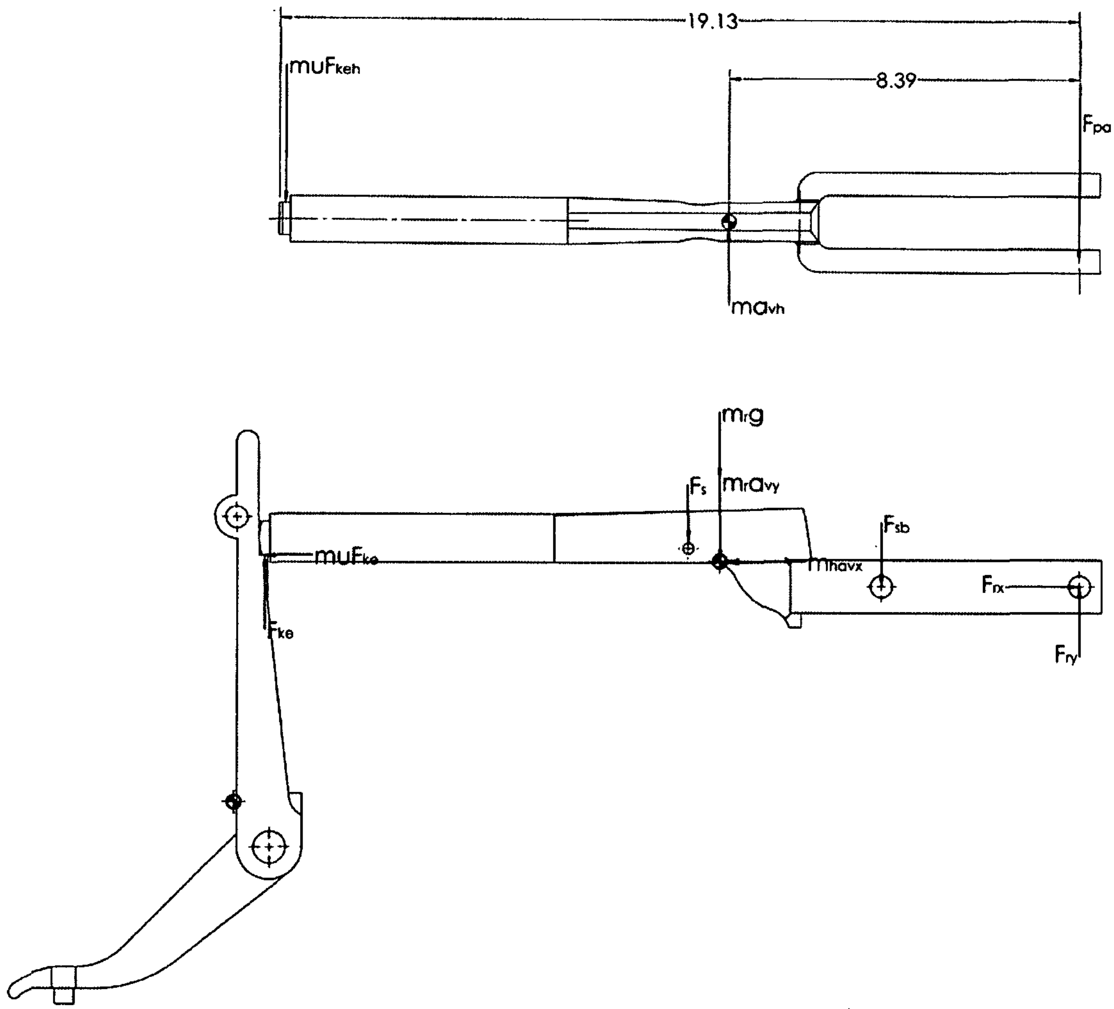


Figure 3-9 Free Body Diagrams for Lateral Motion of Resetting Lever

5.0 CALCULATION

5.1 Approach

This calculation will estimate the magnitude of acceleration required to cause the Hand Trip Lever to disengage from the Reset Lever and trip the Auxiliary Feedwater Pump. Equivalent static methods will be used. Moments will be summed about the pivot point for the Hand Trip Lever to determine the acceleration where the resulting inertial moments exceed the moment associated with the friction force. Since the friction force is a function of the normal force at the knife edge/latch interface, and since that normal force is also a function of the acceleration, an iterative process will be used as follows.

1. A free body diagram of the Reset Lever will be used to sum the moments about the Reset Lever pivot point to determine the normal force between the knife edge of the Reset Lever and the latch plate of the Hand Trip Lever. Assumed values of acceleration on the Reset Arm will be used to determine the normal force. For simplicity, the horizontal acceleration and the vertical acceleration will be assumed to be equal. The directions of the accelerations will be chosen such that the resulting moments on the Hand Trip Lever are counterclockwise (i.e., disengagement direction).

2. Given the calculated normal force, a friction force between the knife edge and latch will be calculated using three assumed values of μ, μ_{dry} =0.8, μ_{lub}=0.16 and μ_{min}=0, which correspond to un-lubricated, lubricated and zero friction conditions.

3. Moments about the pivot point of the Hand Trip Lever will be taken using the assumed values of acceleration. The assumed values of acceleration will be iterated until the acceleration values for each of the assumed values of μ is determined where the sum of the moments about the pivot point is zero. The acceleration value where the moments equal zero is the acceleration required to overcome the friction force and trip the hand lever.

4. The calculated values of acceleration will be compared to measured values of acceleration to determine if the measured values are sufficient to result in trip of the mechanism. (Note that in this calculation, the iterative process will not be document, i.e., the final acceleration values will be assumed and the iteration to arrive at these values will not be shown.)

5.2 Calculation of Knife Edge Forces

To determine the spring force, F_S, on the Resetting Lever, the free lengths and spring rate of the two springs in parallel must be used with the installed spring length.

$l_{s.free} := 3.5625\,in$ — spring free length, Ref. 4

$k_{s.1} := 35.65\,\frac{lbf}{in}$ — measured outer spring rate, Ref. 6, page 4

$k_{s.2} := 13.1\,\frac{lbf}{in}$ — measured inner spring rate, Ref. 6, page 5

$l_{s.installed} := 6.875\,in$ — installed spring length, Ref. 5

$$F_s := \left(l_{s.installed} - l_{s.free}\right)\cdot\left(k_{s.1} + k_{s.2}\right)$$

$$F_s = 161.48\,lbf$$

To determine the spring force from the spring that backseats the shutoff valve disc, F_{sb}, the free length and the spring rate must be used with the installed length of the backseat spring.

$l_{sb.free} := 3.125\,in$ — back seat spring free length, Ref. 6

$k_{sb} := 47.85\,\frac{lbf}{in}$ — backseat spring rate, Ref. 6

$l_{sb.installed} := 1.75\,in$ — installed backseat spring length, (measured during walkdown 10/25)

$$F_{sb} := \left(l_{sb.free} - l_{sb.installed}\right)\cdot k_{sb}$$

$$F_{sb} = 65.79\,lbf$$

The mass of the Resetting Lever, m_r, equals:

$m_r := 6.49\,lb$

The coefficients of friction that will be used are 0.8 for dry, unlubricated conditions (Ref. 3), 0.16 for lubricated conditions (Ref. 3) and zero.

$$\mu := \begin{pmatrix} 0.8 \\ 0.16 \\ 0 \end{pmatrix}$$

Assumed values of acceleration in the downward, a_{vd},and upward, a_{vu}, directions will be as follows:

$$a_{vd} := \begin{pmatrix} 1000g \\ 37.52g \\ 1.85g \end{pmatrix} \qquad a_{vu} := \begin{pmatrix} 36.141g \\ 36.35g \\ 38.07g \end{pmatrix}$$

There are two opposing effects associated with the vertical acceleration. The first effect is that an upward vertical acceleration will reduce the normal force and as a result will reduce the friction force resisting trip. An upward vertical force will also, however, result in a clockwise moment on the Hand Trip Lever which increase the total moment resisting trip. Since these two effects oppose, it is not clear if a upward vertical force is most limiting or a downward vertical force is most limiting. Accordingly, both directions will be evaluated. Note that the most limiting direction for the horizontal acceleration will always be to the left.

Downward Vertical Force

The forces acting on the Resetting Lever can be determined by summing forces and moments shown on the first Free Body Diagram on Figure 3-5.

The force on the Knife Edge of the Resetting Lever for downward acceleration, F_{ked}, can be determined by summing moments about Z at the pin at the right end of the Resetting Lever.

Σ moments on Resetting Lever about Z = 0 (counterclockwise is positive)

$$F_{ked} := \frac{F_s \cdot 9.13 \cdot in + F_{sb} \cdot 4.63 \cdot in + m_r \cdot 1 \cdot g \cdot 8.40 \cdot in + m_r \cdot a_{vd} \cdot 8.40 \cdot in + m_r \cdot a_{vd} \cdot 0.57 \cdot in}{10 \cdot in + 9.13 \cdot in - .07in - \frac{.12}{2} in}$$

$$F_{ked} = \begin{pmatrix} 3160.46 \\ 211.46 \\ 102.17 \end{pmatrix} lbf$$

Using the Free Body Diagram for the Hand Trip Lever on Figure 3-5, the moments about the pivot point can be calculated and the inertial accelerations in the x and y directions respectively, a_{vx} and a_{vy}, that will overcome the friction force between the knife edge and latch can be calculated.

$m_h := 3.21lb$	mass of the hand trip lever as calculated from the solid model
$F_{ts} := 3.65lbf$	F_{ts} is the force from the torsional spring that engages the Hand Trip Lever with the Resetting Lever. As identified in Reference 6, torque provided by this spring was equivalent to a force of 3.65 lbf applied at the centerline of the Resetting Lever (shown in Figure 3-4).

Summing the moments about the pivot of the Hand Trip Lever gives:

$$-F_{ts}\cdot 7.14in - \overrightarrow{\left(\mu\cdot F_{ked}\right)}\cdot 6.75in + \overrightarrow{F_{ked}}\cdot\left(0.25in - .07in - \frac{.12}{2}in\right) \ldots + m_h\cdot a_{vd}\cdot 0.82in + m_h\cdot a_{vd}\cdot 1.06in + m_h\cdot 1g\cdot .82in = \begin{pmatrix} -10675.87 \\ -0 \\ -0 \end{pmatrix} in\cdot lbf$$

The equation above shows that for assumed μ of:

$$\mu = \begin{pmatrix} 0.8 \\ 0.16 \\ 0 \end{pmatrix}$$

coefficient of friction dry
coefficient of friction lubricated
coefficient of friction of zero

left horizontal and downward vertical accelerations of:

$$a_{vd} = \begin{pmatrix} 1000 \\ 37.52 \\ 1.85 \end{pmatrix} g$$

are needed to cause the Hand Trip Lever to disengage and trip the Auxiliary Feedwater Pump Turbine. Note that for the assumed value of μ of 0.8, there is no value of acceleration that will cause the Hand Trip Lever to trip. This is because increased acceleration values needed to put sufficient moment on the Hand Trip Lever to disengage it also increase the applied moment on the Resetting Lever, in turn increasing the normal force, F_{ke}, and the friction force μF_{ke}, resisting disengagement.

Upward Vertical Acceleration

The moment equations for vertical upward acceleration are provided below.

$$F_{keu} := \frac{F_s \cdot 9.13 \cdot in + F_{sb} \cdot 4.63 \cdot in + m_r \cdot 1 \cdot g \cdot 8.40 \cdot in - m_r \cdot a_{vu} \cdot 8.40 \cdot in + m_r \cdot a_{vu} \cdot 0.57 \cdot in}{10 \cdot in + 9.13 \cdot in - .07in - \frac{.12}{2} in}$$

$$-F_{ts} \cdot 7.14in - \overrightarrow{\left(\mu \cdot F_{keu}\right)} \cdot 6.75in + F_{keu} \cdot \left(0.25in - .07in - \frac{.12}{2} in\right) - m_h a_{vu} \cdot 0.82in \ldots + m_h \cdot a_{vu} \cdot 1.06in - m_h \cdot 1g \cdot .82in = \begin{pmatrix} 0 \\ 0 \\ -0 \end{pmatrix} in \cdot lbf$$

The equation above shows that for assumed μ of:

$$\mu = \begin{pmatrix} 0.8 \\ 0.16 \\ 0 \end{pmatrix}$$

coefficient of friction dry
coefficient of friction lubricated
coefficient of friction of zero

left horizontal and upward vertical accelerations of:

$$a_{vu} = \begin{pmatrix} 36.14 \\ 36.35 \\ 38.07 \end{pmatrix} g$$

are needed to cause the Hand Trip Lever to disengage and trip the Auxiliary Feedwater Pump Turbine.

5.3 Knife Edge Latch Contact

The Knife Edge and Latch overlap approximately 0.12 inches as shown in Detail A of Figure 3-4. In the process of inspecting the Knife Edge and Latch, bluing was applied to the Latch to determine the percentage of the Knife Edge that was in contact with the Latch. As documented in Reference 6 (attachment page 3 of 8) only 45% of the Knife Edge overlapping surface was engaged with the Latch. As documented in the attachment to Reference 6, 90% to 100% is considered acceptable. The calculation of forces necessary to trip the linkage in Section 5.2 and the calculation of lateral motion of the Resetting Lever in Section 5.5 of this calculation do not address the degraded contact surface identified in the inspection. The contact is not a variable in these calculations because they are force balances and the calculated forces will be independent of the contact area. The contact pressure between the Knife Edge and Latch, will, however, be impacted by the contact area. The contact area with the as-found 45% contact area will be twice the value of the contact area if the contact area was the desired 90 to 100%. A literature search regarding the impact of contact pressure on the coefficient of friction showed that the coefficient of friction typically increases with increased contact pressure. Accordingly, the increased contact pressure associated with the reduced contact area is expected to make the linkage less likely to trip because the coefficient of friction is increased.

5.4 Vibration Measurements

Vibration measurements were taken during operation of the AFW pump turbine. Measurements were taken with the pump in recirculation mode as well as in operating mode (with the pump providing normal flow to the steam generators). The vibration measurements involved application of transducers to the reset arm as shown in Figure 3-6. Two transducers were employed. The first was put on the top of the end of the Resetting Lever near the knife edge to measure vibration in the vertical direction. In addition, a transducer was placed on the side of the Resetting Lever near the knife edge to measure the vibration in the horizontal plane perpendicular to the axis of the Resetting Lever. The data from the operation of the pump in recirculation mode was used because it bounds the data from operation with flow to the steam generators.

The measured vertical overall root mean square acceleration over the complete frequency range, $a_{v.meas.rms}$, was:

$$a_{v.meas.rms} := 5.74g$$

The measured horizontal overall root mean square acceleration over the complete frequency range, $a_{h.meas.rms}$, was:

$$a_{h.meas.rms} := 1.96g$$

Assuming that the vibration was sinusoidal, the peak acceleration is 1.414 times the RMS acceleration.

$a_{v.meas.peak} := 1.414 \cdot a_{v.meas.rms}$ $\quad$ $a_{h.meas.peak} := 1.414 \cdot a_{h.meas.rms}$

$a_{v.meas.peak} = 8.12g$ $\quad$ $a_{h.meas.peak} = 2.77g$

The highest vertical acceleration at a given frequency occurred at a frequency of 2200 Hz. This RMS vertical spectral acceleration, $a_{V.2200}$ was:

$a_{v.2200.rms} := 2.4g$

As shown on the plots, the total peak (+/-) displacement of the Resetting Arm associated with the vertical vibration was 0.0052 in. Assuming that the vibration was sinusoidal, the peak acceleration is 1.414 times the RMS acceleration.

$a_{v.2200.peak} := 1.414 \cdot a_{v.2200.rms}$

$a_{v.2200.peak} = 3.39g$

The highest horizontal acceleration at a given frequency occurred at a frequency of 1400 Hz. This RMS vertical spectral acceleration, $a_{h.1400}$ was:

$a_{h.1400.rms} := 0.6g$

As shown on the plots, the total peak (+/-) displacement of the Resetting Arm associated with the horizontal vibration was 0.0068 in. Assuming that the vibration was sinusoidal, the peak acceleration is 1.414 times the RMS acceleration.

$a_{h.1400.peak} := 1.414 \cdot a_{h.1400.rms}$

$a_{h.1400.peak} = 0.85g$

5.5 Motion of Resetting Lever in Horizontal Plane

Due to concerns identified by the NRC regarding lateral movement of the Resetting Lever in the horizontal plane in the direction perpendicular to the axis of the Resetting Lever, the measurements identified in Section 5.4 above were taken. The lateral displacement of the Resetting Lever was measured to be 0.0068 inches. Deflection of this magnitude is not significant enough to result in tripping of the mechanism.

To estimate the acceleration required to cause differential relative motion between the Resetting Arm and the Hand Trip Lever, the free body diagrams in Figure 3-9 are used. By summing moments about the pivot point of the Resetting Lever, the acceleration needed to exceed the friction for is calculated.

The acceleration in the horizontal direction perpendicular and parallel to the Resetting Lever axis and the vertical axis are assumed to be the equal and will all be denoted by, $a_{v.h}$.

Since the normal force, F_{keh} and the inertial force on the Resetting lever are a function of $a_{v.h}$, a value of $a_{v.h}$ will be assumed then iterated to determine the appropriate value. Note that for F_{keh}, the accelerations acting on the Resetting Lever are assumed to be acting upward and to the right in order to minimize F_{keh}.

$$a_{v.h} := \begin{pmatrix} 14.51g \\ 4.596g \\ 0g \end{pmatrix}$$

$$F_{keh} := \frac{F_s \cdot 9.13 \cdot in + F_{sb} \cdot 4.63 \cdot in + m_r \cdot 1 \cdot g \cdot 8.40 \cdot in - m_r \cdot a_{v.h} \cdot 8.40 \cdot in - m_r \cdot a_{v.h} \cdot 0.57 \cdot in}{10 \cdot in + 9.13 \cdot in - .07 in - \frac{.12}{2} in}$$

$$F_{keh} = \begin{pmatrix} 52.04 \\ 82.42 \\ 96.5 \end{pmatrix} lbf$$

$$\overrightarrow{(\mu \cdot F_{keh})} \cdot \left(19.13 \cdot in - .07in - \frac{.12}{2} in\right) - m_r \cdot a_{v.h} \cdot 8.40 \cdot in = \begin{pmatrix} 0 \\ -0 \\ 0 \end{pmatrix} in \cdot lbf$$

The results indicate that assuming a coefficient of friction of 0.8 associated with dry, unlubricated conditions, a lateral acceleration of 14.51g is needed to overcome friction between the knife edge and the latch. Assuming a coefficient of 0.16 associated with lubricated conditions, the lateral acceleration needed is 4.60g. Obviously, with a coefficient of friction of 0, there will be relative lateral motion between the knife edge and latch.

It is important to note that the above calculations are performed on an equivalent static basis and do not account for effects of the frequency at which the accelerations are applied. As documented in Section 5.4, the first peak horizontal acceleration measured at the knife edge occurred at a natural frequency of 1400 Hz. This frequency is so high that the acceleration changes direction 1400 times per second. Accordingly, displacement of the knife edge under accelerations at this frequency are very small because before the knife edge can move any significant distance, the acceleration changes direction and results in an inertial force acting in the opposite direction. This is consistent with the measured total acceleration of 0.0068 inches documented in Section 5.4.

5.6 Modal Analysis of Trip Linkage

A modal analysis of the trip linkage was performed to determine its natural frequencies and determine if it had any fundamental modes near the measured peak vibrations documented in Section 5.3. The model shown in Figure 5-1 was used. It included the Hand Trip Lever and the Resetting Lever. Both levers were given cylindrical supports at their pivot points. The cylindrical supports were constrained in the axial and radial directions, but not the tangential directions (i.e., the cylindrical surfaces could not translate, but could rotate about their axis). The constraint provided by the nested springs and backseat spring on the Resetting Lever and the constraint from the torsional spring on the Hand Trip Lever were not modeled. Note that the modal analysis is linear and treats the interface between the knife edge and latch as bonded. This is valid provided acceleration forces are not sufficient to overcome friction forces. These limiting accelerations are calculated in Sections 5.2 and 5.4.

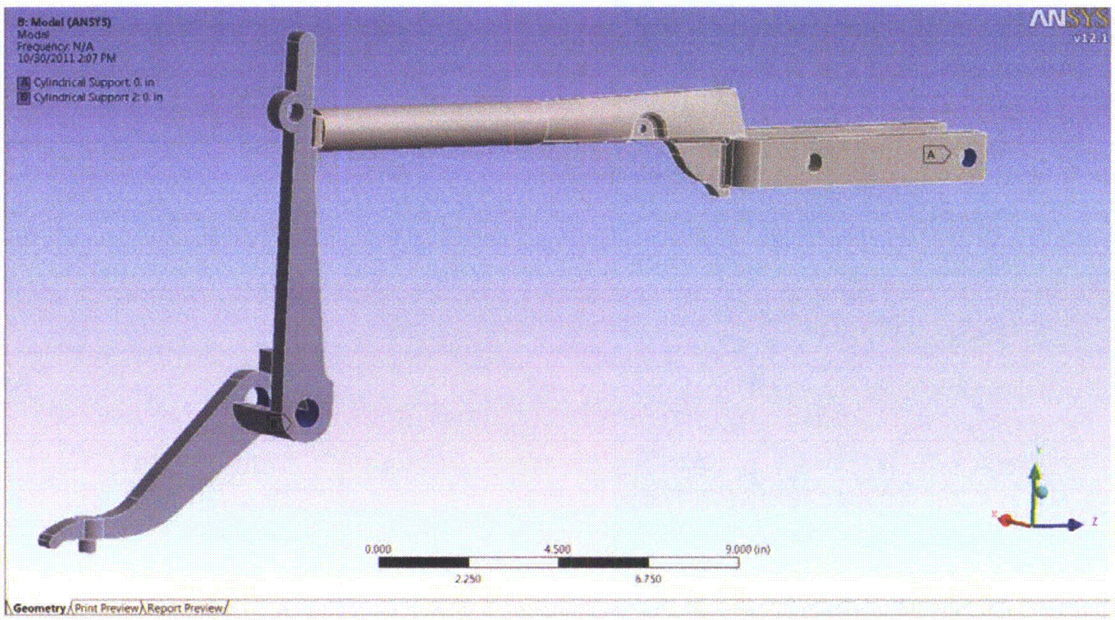


Figure 5-1 Model for Modal Analysis

The modal analysis determined that the first 25 natural frequencies of the linkage are as follows:

MODE	FREQUENCY (HERTZ)
1	229.8966169259
2	261.9191436496
3	425.7514337450
4	596.5167758342
5	624.6537654084
6	965.0003802196
7	993.5813602176
8	1202.745849543
9	1489.231005222
10	1681.107744664
11	2202.627494749
12	2384.383469861
13	2474.200972974
14	2578.803556520
15	2873.830461892
16	2914.930806782
17	3009.936830063
18	3356.535287805
19	3480.042667251
20	3525.019649366
21	3645.234284341
22	4313.871367665
23	4832.755577439
24	4981.113088642
25	5696.331441148

The 9th and 11th modes at 1489 Hz and 2203 Hz, respectively are closest to the measured peak accelerations. The mode shapes for the 9th and 11th modes are shown below in Figures 5-2 and 5-3.

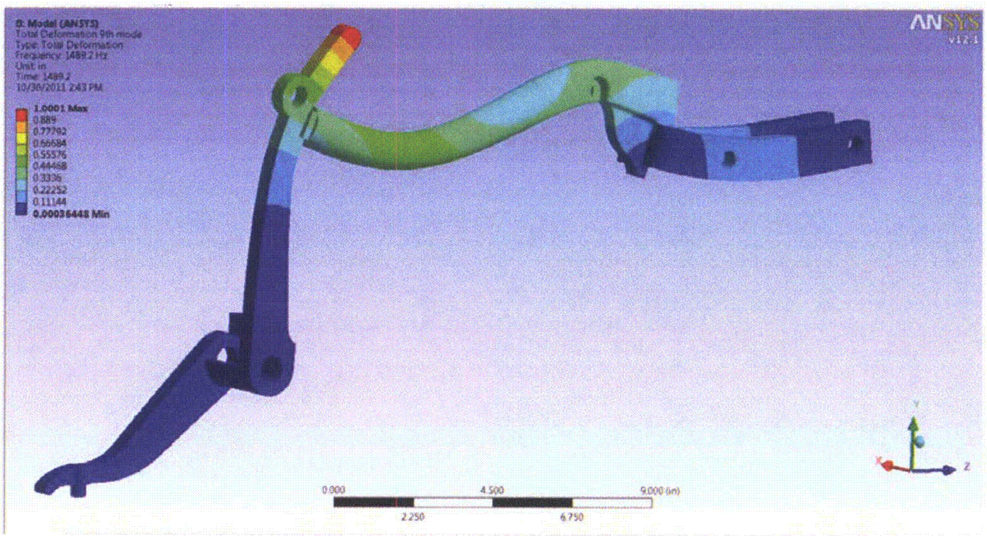


Figure 5-2. 9th Mode Shape at 1489Hz

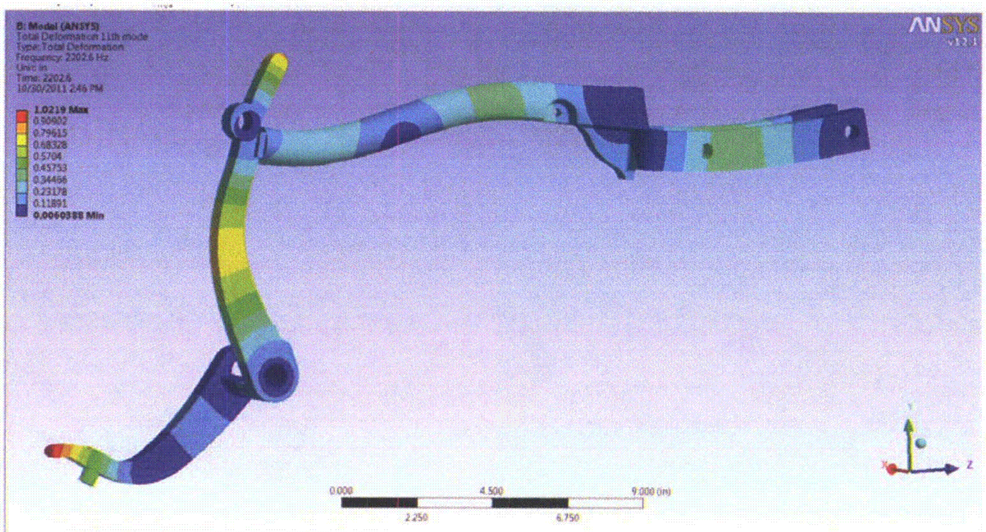


Figure 5-3. 11th Mode Shape at 2203Hz

Review of the mass participation for the 9th and 11th modes indicates that the following percentages of the total mass are participating in each of these nodes.

Mode	Mass Participation (participating mass/total mass)		
	x-direction	y-direction	z-direction
9th	$.44 \times 10^{-7}$	.027	.30
11th	$.33 \times 10^{-6}$	.0078	.079

6.0 REFERENCES

1. Entergy Palisades Condition Report CR-PLP-2011-02350

2. Elliott Technical Manual Prepared for Consumers Power Company for Elliott DYRT Turbine, Revised 5/91.

3. Oberg, Jones, Horton and Ryffel, Machinery's Handbook, 25th Edition, Industrial Press, 1996.

4. Email from S. Kupka (Entergy Operations) to P. Butler (MPR) dated 6/27/2011, "Aux Feed Pump Data."

5. Email from S. Kupka (Entergy Operations) to P. Butler (MPR) dated 6/30/2011, "AFW Pump Trip at Palisades."

6. Email from R. Schmidt (Entergy Operations) to P. Butler (MPR) dated 10/26/2011, 10:02PM, "FW: Scan from a Xerox 4112/4127."

7. Email from J. Jerz (Entergy Operations) to P. Butler (MPR) dated 10/22/2011, 3:13PM, "RE: AFW Pump P-8B Resetting Lever Vibration Data."