

# Dynamic Analysis of a 7 Stage Pump

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## 1 UNDAMPED CRITICAL SPEED ANALYSIS

### 1.1 Pump Model

Fig. 1.1 represents the model of a 7 stage pump generated by the DyRoBes Rotor Dynamics program. In this model, only the main bearings are included. For a critical speed analysis, only an assumed bearing stiffness is required.

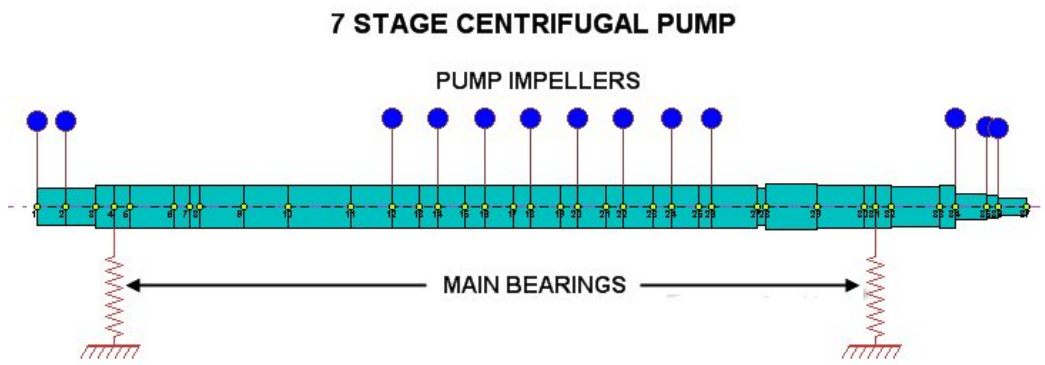


Fig. 1.1 7Stage Centrifugal Pump Model With No Seals

### Selection of Engineering Units

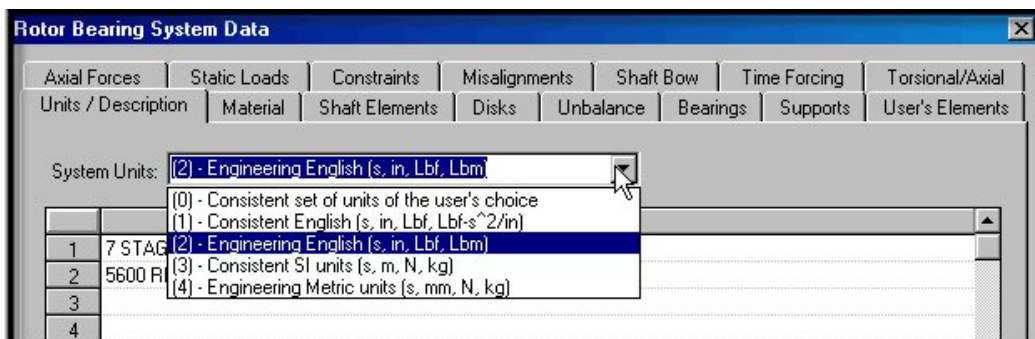


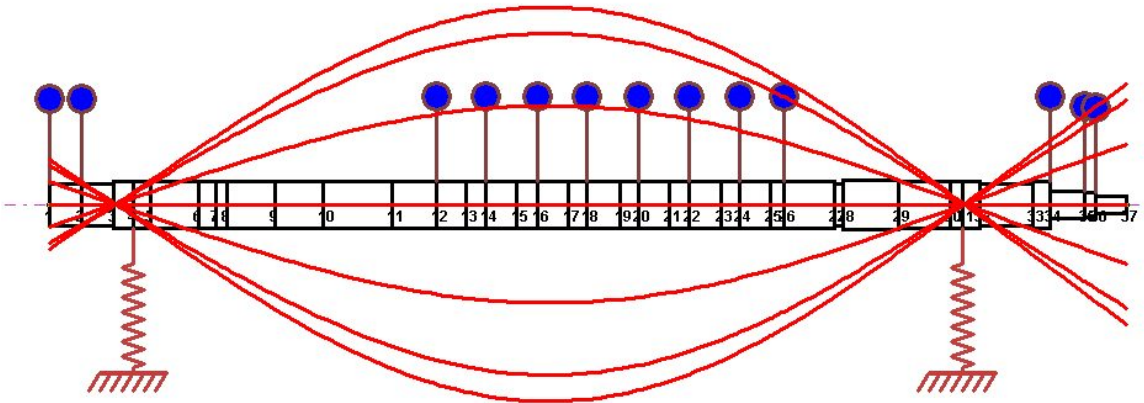
Fig. 1.2 Selection of Units

In the generation of the model, one has the option of using a variety of engineering units. In this example, the model was generated using English units 2. Options 2 and 3 are for metric. The identical model generated in metric should yield identical critical speed values.

## 1.2 Critical Speeds-No Seals

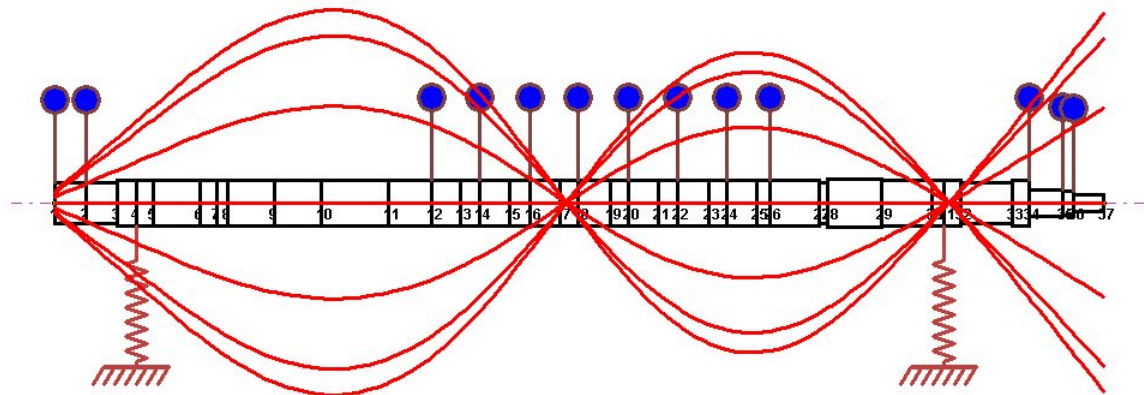
7 STAGE PUMP -CRITICAL SPEED ANALYSIS- NO SEAL EFFECTS  
5600 RPM DESIGN SPEED

Critical Speed Mode Shape, Mode No.= 1  
Spin/Whirl Ratio = 1, Stiffness: Kxx  
Critical Speed = 2007 rpm = 33.45 Hz



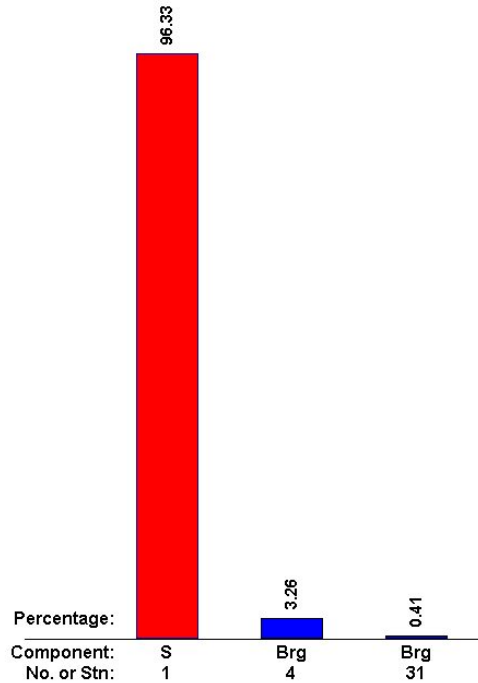
7 STAGE PUMP -CRITICAL SPEED ANALYSIS- NO SEAL EFFECTS  
5600 RPM DESIGN SPEED

Critical Speed Mode Shape, Mode No.= 2  
Spin/Whirl Ratio = 1, Stiffness: Kxx  
Critical Speed = 8772 rpm = 146.21 Hz



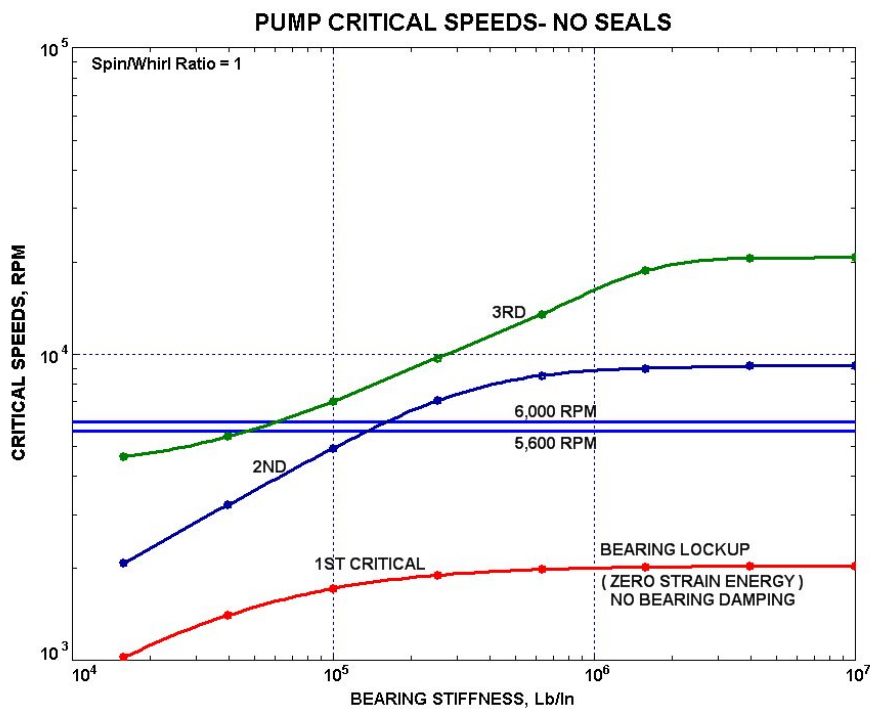
### 1.3 1<sup>st</sup> Mode Strain Energy Distribution

Mode No.= 1, Critical Speed = 2007 rpm = 33.45 Hz  
 Potential Energy Distribution (s/w=1)  
 Overall: Shaft(S)= 96.33%, Bearing(Brg)= 3.67%



The low bearing strain energy indicates that the main bearings have little strain energy and thus the main bearings will not contribute to overall system damping. Hence the choice of rolling element or 3 lobe bearing should make little difference.

### 1.4 Critical Speed Map Without Seals



## 1.5 Pump Model With Seals

7 STAGE PUMP -  
5600 RPM DESIGN SPEED  
WEAR RING SEALS INCLUDED

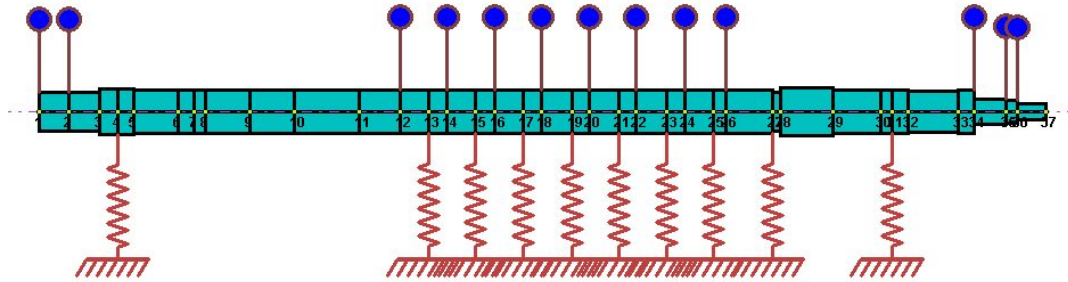
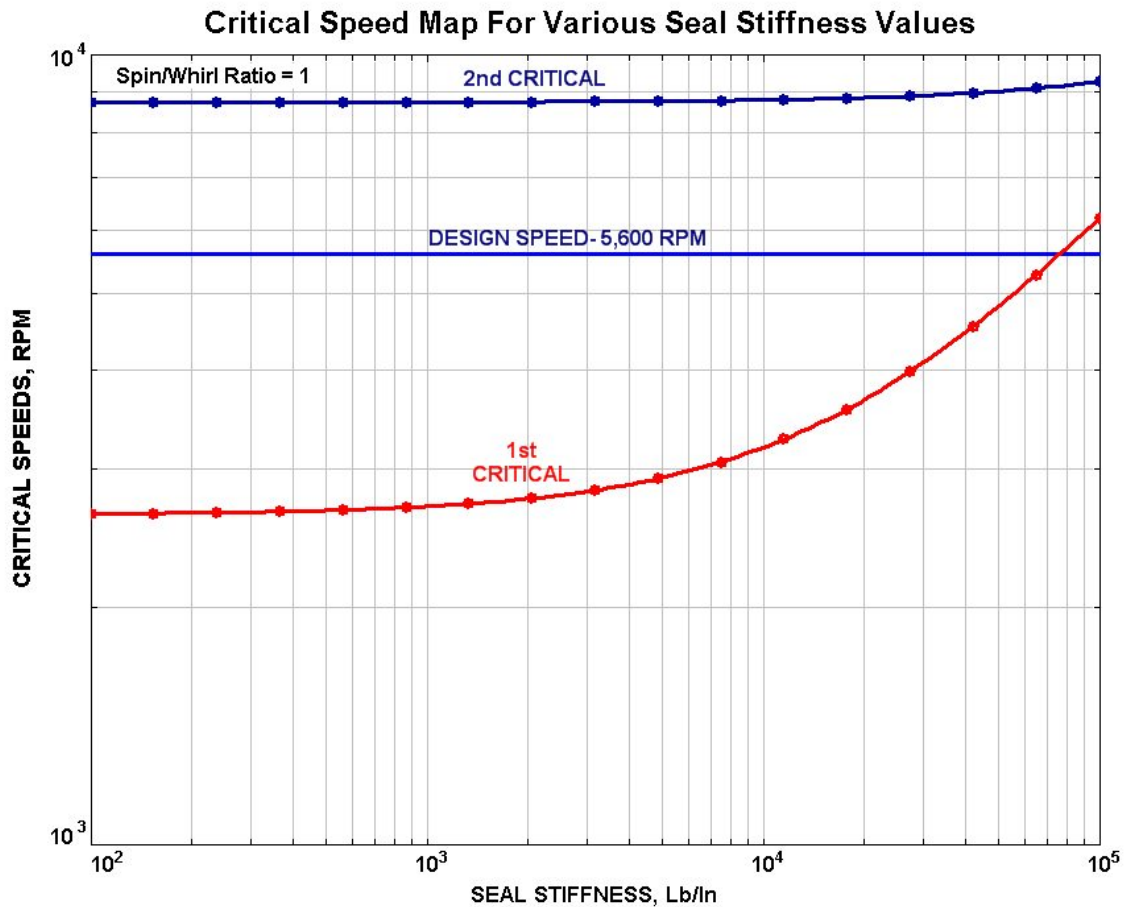


Fig. 1.5 shows the pump model with the 7 seals and balance piston added. These elements are treated as linear bearings. The seal coefficients were precomputed based on operating conditions.

## 1.6 Critical Speed Map With Seals



## 2 DAMPED COMPLEX EIGENVALUE ANALYSIS

### 2.1 Pump Model With Seals and Impeller Moments of Inertia

7 STAGE PUMP -WITH IMPELLER INERTIAS  
5600 RPM DESIGN SPEED  
WEAR RING SEALS INCLUDED

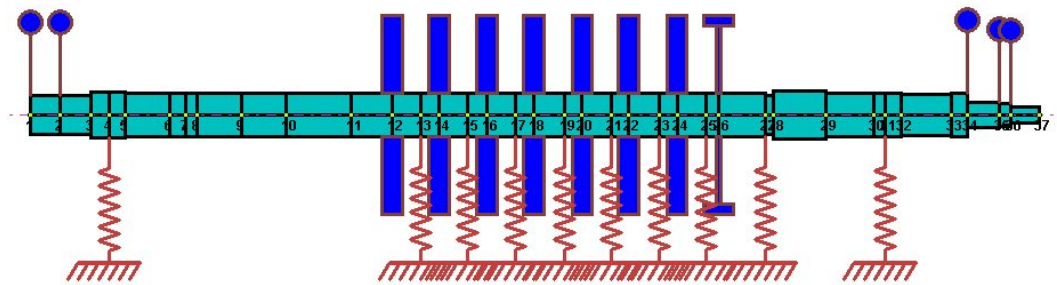


Fig. 2.1 Pump Model With Seals And Impellers

### 2.2 Seal Stiffness and Damping Specification

**Rotor Bearing System Data**

| Axial Forces        | Static Loads | Constraints    | Misalignments | Shaft Bow | Time Forcing | Torsional/Axial |                 |
|---------------------|--------------|----------------|---------------|-----------|--------------|-----------------|-----------------|
| Units / Description | Material     | Shaft Elements | Disks         | Unbalance | Bearings     | Supports        | User's Elements |

Bearing: 3 of 10    Add Brg    Del Brg    Previous    Next

Station I:     J:     Angle:

Type:

Comment:

Translational Bearing Properties

|   |  |  |  |
|---|--|--|--|
| K <sub>xx</sub> : <input type="text" value="34551"/>  | K <sub>xy</sub> : <input type="text" value="37917"/> | C <sub>xx</sub> : <input type="text" value="122.5"/> | C <sub>xy</sub> : <input type="text" value="-5.3"/>  |
| K <sub>yx</sub> : <input type="text" value="-37917"/> | K <sub>yy</sub> : <input type="text" value="10000"/> | C <sub>yx</sub> : <input type="text" value="-5.3"/>  | C <sub>yy</sub> : <input type="text" value="122.5"/> |

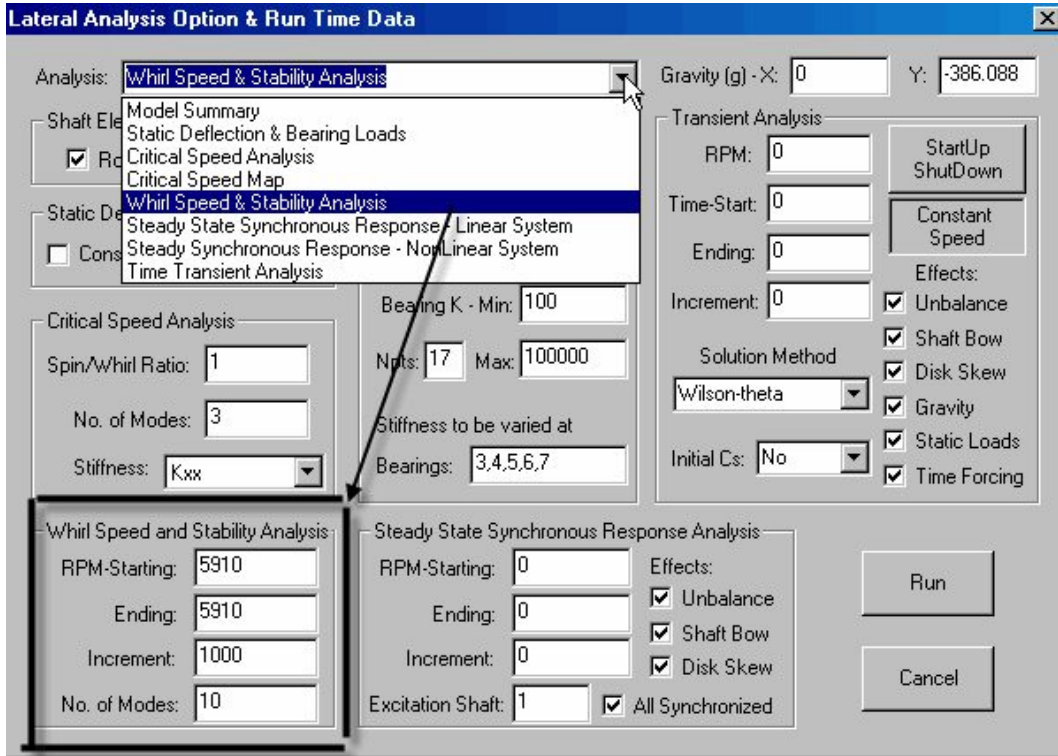
Rotational Bearing Properties

|  |  |  |  |
|--|--|--|--|
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| K <sub>ba</sub> : <input type="text" value="0"/> | K <sub>bb</sub> : <input type="text" value="0"/> | C <sub>ba</sub> : <input type="text" value="0"/> | C <sub>bb</sub> : <input type="text" value="0"/> |

Unit(2) - Kt: Lbf/in, Ct: Lbf-s/in; Kr: Lbf-in, Cr: Lbf-in-s

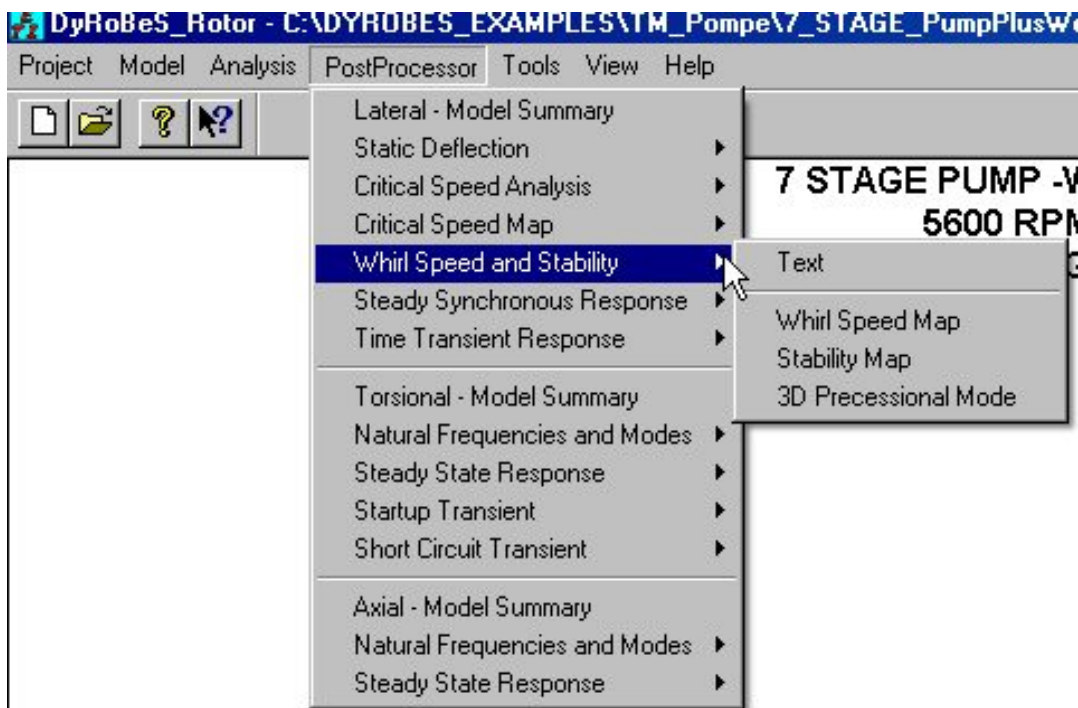
### 2.3 Dynamics Analysis Options-Whirl Speed & Stability Analysis

After a model is generated, Fig 2.3 represent the various options available. In this case the option of Whirl Speed & Stability Analysis is chosen. This option computes the system complex eigenvalues. In this example, the damped modes are computed for a speed of 5910 RPM.



### 2.4 Postprocessing Options For Whirl Speed & Stability Analysis

After the complex modes are computed, the next procedure is to select the PostProcessor option. The option of 3D Precessional Mode is selected in order to show the mode shape and damping.



## 2.5 Dimensional Complex Mode Shapes

7 STAGE PUMP -WITH IMPELLER INERTIAS  
 5600 RPM DESIGN SPEED  
 WEAR RING SEALS INCLUDED  
 Precessional Mode Shape - STABLE FORWARD Precession  
 Shaft Rotational Speed = 5910 rpm, Mode No.= 1  
 Whirl Speed (Damped Natural Freq.) = 3341 rpm, Log. Decrement = 0.8090

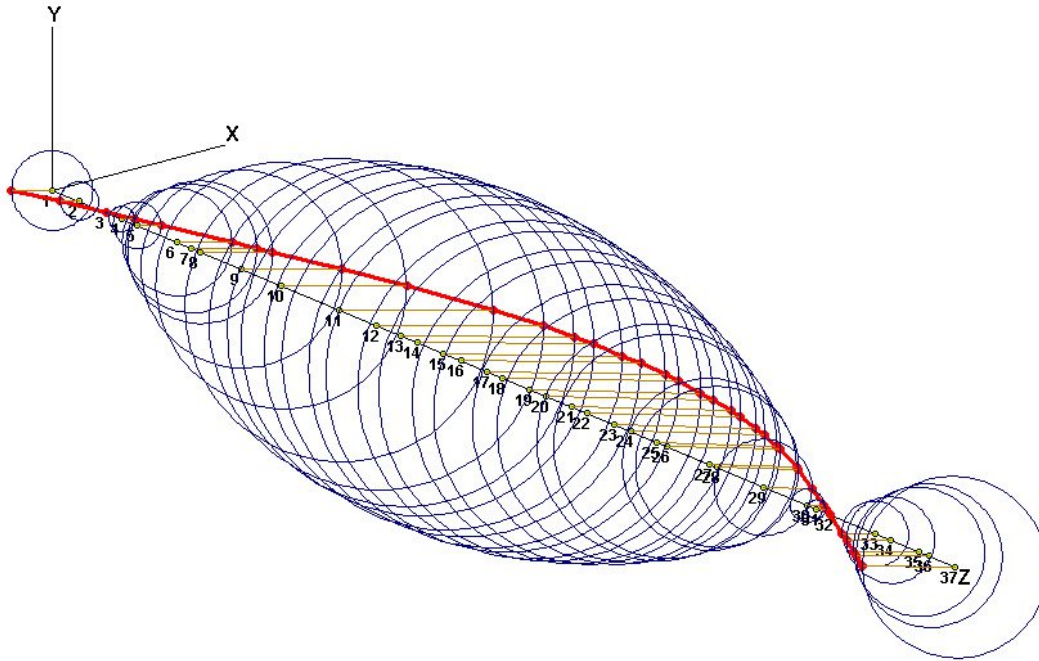


Fig. 2.5-1 1<sup>st</sup> Forward Whirl Mode at 3341 CPM, Log Decrement=0.8, Mode 1

7 STAGE PUMP -WITH IMPELLER INERTIAS  
 5600 RPM DESIGN SPEED  
 WEAR RING SEALS INCLUDED  
 Precessional Mode Shape - STABLE BACKWARD Precession  
 Shaft Rotational Speed = 5910 rpm, Mode No.= 2  
 Whirl Speed (Damped Natural Freq.) = 3428 rpm, Log. Decrement = 9.1936

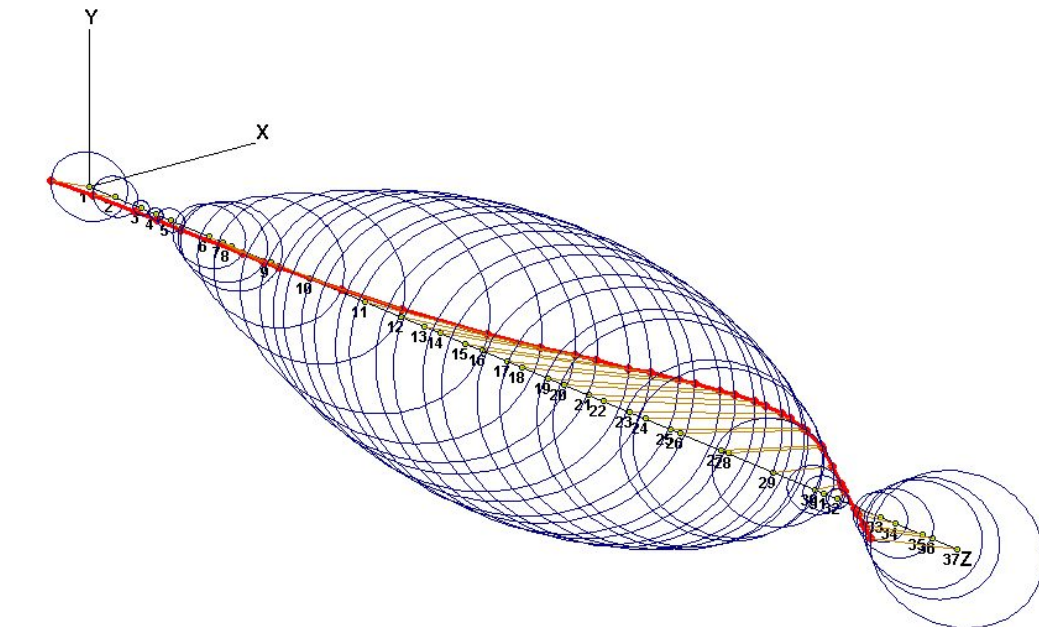
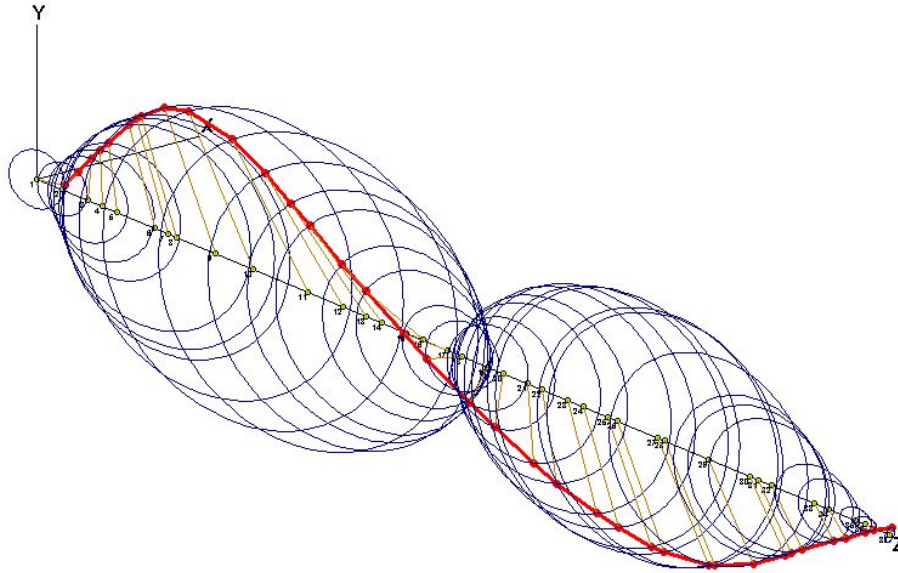


Fig. 2.5-2 1<sup>st</sup> Backward Whirl Mode at 3428 CPM, Log Dec=9.19, Mode 2

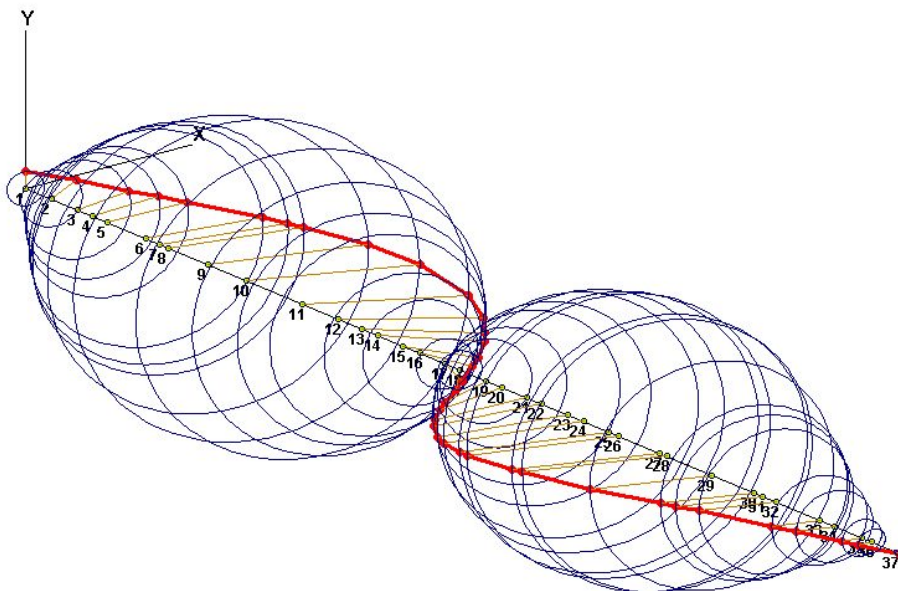
## 2.5 Dimensional Complex Mode Shapes

7 STAGE PUMP -WITH IMPELLER INERTIAS  
5600 RPM DESIGN SPEED  
WEAR RING SEALS INCLUDED  
Precessional Mode Shape - STABLE BACKWARD Precession  
Shaft Rotational Speed = 5910 rpm, Mode No.= 3  
Whirl Speed (Damped Natural Freq.) = 8033 rpm, Log. Decrement = 1.9648



**Fig. 2.5-3 2<sup>nd</sup> Backward Mode at 8033 CPM, Log Dec=1.96, Mode 3**

7 STAGE PUMP -WITH IMPELLER INERTIAS  
5600 RPM DESIGN SPEED  
WEAR RING SEALS INCLUDED  
Precessional Mode Shape - STABLE FORWARD Precession  
Shaft Rotational Speed = 5910 rpm, Mode No.= 4  
Whirl Speed (Damped Natural Freq.) = 8522 rpm, Log. Decrement = 0.9763



**Fig. 2.5-4 2<sup>nd</sup> Forward Mode at 8522 CPM, Log Dec=0.97, Mode 4**

### **3 Summary and Conclusions**

1. Pump on main bearings only has a low critical speed around 2,000 rpm.
2. Since strain energy in main bearings is low, bearing type will have little influence on response.
3. There are only 4 damped eigenvalues below 10,000 rpm. These are the first 2 forward and backward modes. Only the first forward mode is of interest.
4. The backward modes are of no interest since they cannot be excited.
5. The first forward mode is at 3342 CPM and is well damped. It should present no problem as long as the seals are active.
6. Pump operation in dry state will result in seal wear and damage due to lack of system damping.
7. Seals may act as plain bearings under low pressure differential instead of axial flow turbulent seals. This could cause whirling in the first modes.
8. Instrumentation could be added to shaft end to monitor for whirling conditions under low seal pressure drop.
9. Previous eigenvalue analysis appears to be unreliable with nonexistent modes.