**Experiment 9: DYNAMICS LAB**

**CENTRIFUGAL FORCE AND WHIRLING OF SHAFT APPARATUS**

**BACKGROUND:**

In physics, the history of centrifugal and centripetal forces illustrates a long and complex evolution of thought about the nature of forces, relativity, and the nature of physical laws.

Early scientific ideas about centrifugal force were based upon intuitive perception, and circular motion was considered somehow more "natural" than straight-line motion. According to Domenico Bertoloni-Meli:

"For Huygens and Newton, centrifugal force was the result of a curvilinear motion of a body; hence it was located in nature, in the object of investigation. According to a more recent formulation of classical mechanics, centrifugal force depends on the choice of how phenomena can be conveniently represented. Hence it is not located in nature, but is the result of a choice by the observer. In the first case a mathematical formulation mirrors centrifugal force; in the second it creates it."

In Newtonian mechanics, the centrifugal force is an inertial force (also called a "fictitious" or "pseudo" force) that appears to act on all objects when viewed in a rotating frame of reference. It is directed away from an axis passing through the coordinate system's origin and parallel to the axis of rotation. If the axis of rotation passes through the coordinate system's origin, the centrifugal force is directed radially outwards from that axis. The concept of centrifugal force can be applied in rotating devices, such as centrifuges, centrifugal pumps, centrifugal governors, and centrifugal clutches, and in centrifugal railways, planetary orbits and banked curves, when they are analyzed in a rotating coordinate system. The term has sometimes also been used for the reactive centrifugal force that is a reaction to a centripetal force. The effect of centrifugal force in countering gravity, as in this behavior of the tides, has led centrifugal force sometimes to be called "false gravity" or "imitation gravity" or "quasi-gravity".

**AIM OF STUDY:** Analysis of Centrifugal Force using Centrifugal Force apparatus bell crank.

**LABORATORY EQUIPMENT:** Bell Crank, Various masses are provided, Stop watch, Counter and Power supply.**CHECK FOR COUNTER NAME AGAIN IN LAB.**

**EXPERIMENTAL PROCEDURE:** First Experiment Procedure:

1. Attach two masses (Mb) of equal magnitude to the horizontal arms of the apparatus.
2. Attach two masses (Ma) of equal magnitude to the vertical arms of the apparatus.
3. Lock the masses to the bell brackets with their lock nuts.
4. Lock the two brackets C at equal distance r from the center Y, with the locating pins.
5. Start the motor and very slowly and evenly increase the speed until the two bell-cranks snap over from stop D to stop E. You will hear a click. At this precise moment, leave the speed control stationary.
6. Simultaneously start a stopwatch and the magnetic revolution counter on the control box. With these, we will be able to calculate the angular speed of the rotating arm.
7. After a time lapse of 20secs, stop the stopwatch and the revolution counter simultaneously and read the time duration t, and the number of revolutions.
8. With the mass Mb, and distance r, constant, change the value of Ma and repeat 2 – 7.

Second Experiment Procedure:

1. Attach two masses (Mb) of equal magnitude to the horizontal arms of the apparatus.
2. Attach two masses (Ma) of equal magnitude to the vertical arms of the apparatus.
3. Lock the masses to the bell brackets with their lock nuts.
4. Lock the two brackets C at equal distance r from the center Y, with the locating pins.
5. Start the motor and very slowly and evenly increase the speed until the two bell-cranks snap over from stop D to stop E. You will hear a click. At this precise moment, leave the speed control stationary.
6. Simultaneously start a stopwatch and the magnetic revolution counter on the control box. With these, we will be able to calculate the angular speed of the rotating arm.
7. After a time lapse of 20secs, stop the stopwatch and the revolution counter simultaneously and read the time duration t, and the number of revolutions.
8. With the mass Ma, and distance r, constant, change the value of Mb, and repeat 2 – 7.

Third Experiment Procedure:

1. Attach two masses (Mb) of equal magnitude to the horizontal arms of the apparatus.
2. Attach two masses (Ma) of equal magnitude to the vertical arms of the apparatus.
3. Lock the masses to the bell brackets with their lock nuts.
4. Lock the two brackets C at equal distance r from the center Y, with the locating pins.
5. Start the motor and very slowly and evenly increase the speed until the two bell-cranks snap over from stop S to stop E. You will hear a click. At this precise moment, leave the speed control stationary.
6. Simultaneously start a stopwatch and the magnetic revolution counter on the control box. With these, we will be able to calculate the angular speed of the rotating arm.
7. After a time lapse of 20secs, stop the stopwatch and the revolution counter simultaneously and read the time duration t, and the number of revolutions.
8. With the mass Mb, and mass Ma, constant, change the value of the distance r by moving the bell bracket to the next hole on the arm; and repeat 2 – 7.

**RESULTS AND CALCULATIONS:** For 1st Experiment:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Mb = 0.3(kg) | r = 0.19(m) |  | ω2 | (rad/sec)2 |  |
| Ma(kg) | Counter(rev) | Time(sec) | Theoretical | Practical | 1/Ma(kg-1) |
| 0.6 | 22 | 20 | 44.26 | 47.77 | 1.667 |
| 0.7 | 21 | 20 | 37.93 | 43.52 | 1.428 |
| 0.5 | 24 | 20 | 53.11 | 56.85 | 2.000 |
| 0.8 | 20 | 20 | 33.19 | 39.48 | 1.350 |

For 2nd Experiment:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Ma = 0.8(kg) | r = 0.19(m) |  | ω2 | (rad/sec)2 |  |
| Mb(kg) | Counter(rev) | Time(sec) | Theoretical | Practical | 1.714Mbg() |
| 0.3 | 20 | 20 | 33.19 | 39.48 | 5.045 |
| 0.4 | 22 | 20 | 44.26 | 47.77 | 6.727 |
| 0.5 | 24 | 20 | 55.32 | 56.85 | 8.409 |
| 0.6 | 26 | 20 | 66.38 | 66.72 | 10.091 |

For 3rd Experiment:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Ma = 0.8(kg) | Mb =0.6(kg) |  | ω2 | (rad/sec)2 |  |
| r(m) | Counter(rev) | Time(sec) | Theoretical | Practical | 1/r(m-1) |
| 0.19 | 26 | 20 | 66.38 | 66.72 | 5.263 |
| 0.16 | 28 | 20 | 78.83 | 77.38 | 6.250 |
| 0.13 | 32 | 20 | 97.02 | 101.06 | 7.692 |
| 0.10 | 37 | 20 | 126.13 | 135.11 | 10.000 |

**WHIRLING OF SHAFT**

**BACKGROUND:** Whirlingspeed is also called as Critical speed of a shaft. It is defined as the speed at which a rotating shaft will tend to vibrate violently in the transverse direction if the shaft rotates in horizontal direction. In other words, the whirling or critical speed is the speed at which resonance occurs. Whirling Speed is due to the unbalanced forces acting on a rotating shaft.

In the field of rotor dynamics, the critical speed is the theoretical angular velocity which excites the natural frequency of a rotating object, such as a shaft, propeller or gear. As the speed of rotation approaches the objects natural frequency, the object begins to resonate which dramatically increases system vibration. The resulting resonance occurs regardless of orientation.

**RESULTS AND CALCULATIONS:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | END | CONDITION: | FREE- | FREE |  | F1 first | mode | F2 | second |
| Shaft | Dia | Length |  | W | I | (rpm) |  | mode | (rpm) |
| NO. | (mm) | mm | m | (N/m) | (mm4) | Measured | Theoretical | Measured | Theoretical |
| 1 | 3 | 600 | 0.6 | 0.5687 | 3.977 | 783.62 | 787.56 | 1568.74 | 1576.62 |
| 2 | 3 | 900 | 0.9 | 0.5687 | 3.977 | 348.29 | 350.04 | 697.18 | 700.68 |
| 3 | 6 | 600 | 0.6 | 2.2749 | 63.63 | 1567.13 | 1575.00 | 3137.29 | 3153.06 |
| 4 | 6 | 900 | 0.9 | 2.0474 | 63.63 | 734.19 | 737.88 | 1469.75 | 1477.14 |
| 5 | 7 | 600 | 0.6 | 3.0964 | 117.87 | 1828.25 | 1837.44 | 3659.97 | 3678.36 |
| 6 | 7 | 900 | 0.9 | 3.0964 | 117.87 | 812.58 | 816.66 | 1626.65 | 1634.82 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | END | CONDITION: | FIXED |  |  | F1 first | Mode | F2 | Second |
| Shaft | Dia | Length |  | W | I | (rpm) |  | mode | (rpm) |
| NO. | (mm) | mm | M | (N/m) | (mm4) | Measured | Theoretical | Measured | Theoretical |
| 1 | 3 | 600 | 0.6 | 0.5687 | 3.977 | 1205.46 | 1211.52 | 1856.13 | 1865.46 |
| 2 | 3 | 900 | 0.9 | 0.5687 | 3.977 | 535.75 | 538.44 | 824.93 | 829.08 |
| 3 | 6 | 600 | 0.6 | 2.2749 | 63.63 | 2410.81 | 2422.92 | 3712.09 | 3730.74 |
| 4 | 6 | 900 | 0.9 | 2.0474 | 63.63 | 1129.40 | 1135.08 | 1739.06 | 1747.80 |
| 5 | 7 | 600 | 0.6 | 3.0964 | 117.87 | 2812.41 | 2826.54 | 4330.58 | 4352.34 |
| 6 | 7 | 900 | 0.9 | 3.0964 | 117.87 | 1249.94 | 1256.22 | 1924.67 | 1934.34 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | END | CONDITION: | CANTI | LEVER |  | F1 first | Mode | F2 | second |
| Shaft | Dia | Length |  | W | I | (rpm) |  | mode | (rpm) |
| NO. | (mm) | mm | M | (N/m) | (mm4) | Measured | Theoretical | Measured | Theoretical |
| 1 | 3 | 600 | 0.6 | 0.5687 | 3.977 | 1036.45 | 1041.66 | --- | --- |
| 2 | 3 | 900 | 0.9 | 0.5687 | 3.977 | 460.65 | 462.96 | --- | --- |
| 3 | 6 | 600 | 0.6 | 2.2749 | 63.63 | 2072.78 | 2083.20 | --- | --- |
| 4 | 6 | 900 | 0.9 | 2.0474 | 63.63 | 971.08 | 975.96 | --- | --- |
| 5 | 7 | 600 | 0.6 | 3.0964 | 117.87 | 2418.09 | 2430.24 | --- | --- |
| 6 | 7 | 900 | 0.9 | 3.0964 | 117.87 | 1074.72 | 1080.12 | --- | --- |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | END | CONDITION | FIXED | FREE |  | F1 first | Mode | F2 | second |
| Shaft | Dia | Length |  | W | I | (rpm) |  | mode | (rpm) |
| NO. | (mm) | mm | M | (N/m) | (mm4) | Measured | Theoretical | Measured | Theoretical |
| 1 | 3 | 600 | 0.6 | 0.5687 | 3.977 | 980.04 | 984.96 | 1763.30 | 1772.16 |
| 2 | 3 | 900 | 0.9 | 0.5687 | 3.977 | 435.57 | 437.76 | 783.68 | 787.62 |
| 3 | 6 | 600 | 0.6 | 2.2749 | 63.63 | 1960.01 | 1969.86 | 3526.48 | 3544.2 |
| 4 | 6 | 900 | 0.9 | 2.0474 | 63.63 | 918.25 | 922.86 | 1652.14 | 1660.44 |
| 5 | 7 | 600 | 0.6 | 3.0964 | 117.87 | 2286.57 | 2298.06 | 4113.99 | 4134.66 |
| 6 | 7 | 900 | 0.9 | 3.0964 | 117.87 | 1016.27 | 1021.38 | 1828.43 | 1837.62 |

**OBSERVATIONS:**

**PRECAUTIONS:**

**CONCLUSION**