PELTON WHEEL TURBINE LAB

PURPOSE: The main purpose of this lab is to measure the power output of a Pelton Wheel turbine and to compare this to the theoretical power output. Another purpose of the lab is to check turbine scaling laws.

PROCEDURE: Set the driving pressure at a low level. Measure the flow rate through the turbine. Set the brake at some level and measure the brake load using the load cell and the rotor speed using a tachometer. Repeat for various brake settings. Set the driving pressure at a high level and repeat the experiment.

REPORT: Using the measured data, calculate the brake torque and the bucket speed: then calculate the brake power output of the turbine. Plot Power $P$ versus RPM for each driving pressure. Plot Power Coefficient $C_p$ versus Speed Coefficient $C_s$. Compare Actual Power with Theoretical Power. Comment on the results.
MEASUREMENTS

The brake power output of the turbine is:

\[ P = T \omega \]

where \( T \) is the torque on the rotor and \( \omega \) is the rotational speed of the rotor. The torque is:

\[ T = L d \]

where \( L \) is load measured by the brake load cell and \( d \) is the moment arm of the cell from the rotor axis. The rotor speed \( \omega \) is measured using a tachometer.

The theoretical power is a function of the bucket speed \( V_B \) and the jet speed \( V_J \). The bucket speed is:

\[ V_B = R \omega \]

where \( R \) is the distance out to the bucket from the rotor axis. The jet speed is approximately:

\[ V_J = k \sqrt{2P/\rho} \]

where \( k \) is a nozzle loss factor, \( \rho \) is the density of water and \( P \) is the jet driving pressure: this is measured using a pressure gage. For the lab turbine, \( k \) is 0.97, \( d \) is 15cm and \( R \) is 5cm.
PELTON WHEEL TURBINE THEORY

The power output of the turbine is:

\[ P = T \omega \]

where \( T \) is the torque on the rotor and \( \omega \) is the rotational speed of the rotor. The torque is:

\[ T = \Delta (\rho Q V_T R) \]

where \( Q \) is the volumetric flow rate through the turbine and \( V_T \) is the tangential flow velocity. The tangential flow velocities at inlet and outlet are:

\[ V_{IN} = V_J \quad V_{OUT} = (V_J - V_B) K \cos \beta + V_B \]

where, relative to the tangential direction, \( \beta \) is the angle of the relative velocity vector and \( K \) is a loss factor. So power becomes:

\[ P = \rho Q (V_J - V_B) (1 - K \cos \beta) V_B \]

For the lab turbine, \( \beta \) is 168° and \( K \) is 0.8. In the lab, the flow rate \( Q \) is measured using a V Notch Weir.
For turbines, we are interested mainly in the power of the device as a function of its rotational speed. The simplest way to develop a nondimensional power is to divide power $P$ by something which has the units of power. The power in a flow is equal to its dynamic pressure $P$ times its volumetric flow rate $Q$:

$$P \cdot Q$$

So, we can define a power coefficient $C_P$:

$$C_P = \frac{P}{P \cdot Q}$$

For a Pelton Wheel turbine, the dynamic pressure $P$ is approximately equal to the driving pressure.

To develop a nondimensional version of the rotational speed of the turbine, we can divide the tip speed of the blades $R\omega$ by the flow speed $U$. For a Pelton Wheel turbine, the flow speed $U$ is equal to the jet speed $V_J$. So, we can define a speed coefficient $C_s$:

$$C_s = \frac{R \omega}{V_J}$$
DATA SHEET FOR PELTON WHEEL TURBINE

JET PRESSURE =

FLOW RATE =

<table>
<thead>
<tr>
<th>RUN</th>
<th>BRAKE LOAD</th>
<th>ROTOR RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DATA SHEET FOR PELTON WHEEL TURBINE

JET PRESSURE =

FLOW RATE =

<table>
<thead>
<tr>
<th>RUN</th>
<th>BRAKE LOAD</th>
<th>ROTOR RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STRAIN AMPLIFIER/SIGNAL CONDITIONER MODULES
FOR STRAIN GAGES, LOAD CELLS, AND TRANSDUCERS

DMD-460 Series

- Starts at $350

- Bridge Excitation
  4 to 15 Vdc Up to 120 mA
- Works with 120, 350, 500 Ω and Greater
  Bridge Circuits
- Adjustable Gain and Offset
- 6-Wire Bridge Connections
- Voltage and Current
  Output Versions
- 115 and 230 Vac, and
  DC-Powered Models

The DMD-460 Series bridge amplifiers are self-contained, AC- or DC-powered, signal conditioning modules for strain gages, load cells, and bridge-type sensors. The DMD-465 contains a precision differential instrumentation amplifier with voltage output. The similar DMD-465WB has a frequency response to 2 kHz, while the DMD-466 has a 4 to 20 mA output instead of a voltage output.

SPECIFICATIONS

COMMON
- Power: Standard 115 Vac or
  optional 240 Vac ±10% 50/60 Hz or
  10 to 35 Vac 0.7 A @ 10 V, 0.17 A @ 35 V at maximum excitation load
- Operating Temperature: 0 to 70°C
  (32 to 158°F)
- Storage Temperature: -25 to 85°C
  (-13 to 185°F)
- Weight: 310 g (11 oz)
- Size: 96 L x 51 W x 73 mm H
  (3.75 x 2 x 2.87"

BRIDGE SUPPLY
- Excitation Voltage Range: 4 to 15 Vdc
- Current Output: 120 mA max
- Line and Load Regulation:
  (0 to 100 mA) 0.05% max
- Output Noise: 0.5 mV rms

VOLTAGE OUTPUT
- DMD-465 and DMD-465WB
  Gain Range: 4 to 250 (up to 1000 with
  external resistor on DMD-465 only)

Dynamic Response:
- DMD-465: DC to -3 dB = 3 Hz
- DMD-465WB: DC to -3 dB = 2 kHz
- Max Output (2 kΩ Load): ±10 Vdc
- Output Impedance: 0.01 to 1 Ω
- Output Offset: ±5 to 2 V
- Gain Temp Coefficient: 200 ppm/°C
- Input Bias Current: ±30 nA
- Input Impedance: 3000 MΩ
- Dynamic Response: DC to -3 dB = 3 Hz

Input Range for 20 mA Output:
- 10 mV rms, 50 mV max
- Zero Adjust: 0 to ±12 mA
- Linearity: ±0.05%, FS
- Temperature Stability: 200 ppm/°C
- Input Impedance: 1000 MΩ
- Common-Mode Rejection: 50 dB
- Common-Mode Input Voltage: ±15 V
- Compliance Voltage: 10 Vdc
- Output Noise: ±1 μA rms @ gain
  0.2 mV, 1 to 100 Hz

MOST POPULAR MODELS HIGHLIGHTED!

To Order (Specify Model Number)

<table>
<thead>
<tr>
<th>MODEL NO.</th>
<th>PRICE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD-465</td>
<td>$350</td>
<td>Voltage output</td>
</tr>
<tr>
<td>DMD-465-220V</td>
<td>350</td>
<td>220 Vac powered DMD-465</td>
</tr>
<tr>
<td>DMD-465WB</td>
<td>350</td>
<td>High-frequency voltage output</td>
</tr>
<tr>
<td>DMD-465WB-220V</td>
<td>350</td>
<td>220 Vac powered DMD-465WB</td>
</tr>
<tr>
<td>DMD-466</td>
<td>350</td>
<td>Current output (4 to 20 mA)</td>
</tr>
<tr>
<td>DMD-466-220V</td>
<td>350</td>
<td>220 Vac powered DMD-466</td>
</tr>
<tr>
<td>DMD-466DC</td>
<td>395</td>
<td>10 to 20 mA, 100 Vdc powered DMD-466</td>
</tr>
</tbody>
</table>

ACCESSORY

<table>
<thead>
<tr>
<th>MODEL NO.</th>
<th>PRICE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE-2454</td>
<td>$160</td>
<td>Reference Book: The Industrial Electronics Handbook</td>
</tr>
</tbody>
</table>
1" DIAMETER STAINLESS STEEL COMPRESSION LOAD CELL
0-100 lb TO 0-10,000 lb CAPACITIES

LC304 Series
Compression
0-25 lb to 0-10,000 lb
0-11 kg to 0-4537 kg
1 Newton = 0.2248 lb
calibration = 10 Newtons
1 lb = 454 g
1 t = 1000 kg = 2204 lb

All Models $295

- Heavy-Duty Design
- Built-In Load Button for Easy Installation
- Miniature 25 mm (1") Diameter and 25 mm (1") High Case
- 5-Point Calibration Provided

OMEGA's LC304 Series load cells offer the highest output of all miniature load cells. Their small 25 mm (1") diameter makes it easy to mount them in a pocket or on a flat surface. The rugged stainless steel case and high-quality construction ensure reliability.

SPECIFICATIONS
Excitation: 10 Vac, 15 Vdc max
Output: 2 mV/V nominal
Accuracy: ±0.5% FSO linearly, hysteresis, repeatability combined
5-Point Calibration: 0%, 25%, 50%, 75%, 100%
Zero Balance: ±2% FSO
Operating Temp Range: -54 to 107°C (-65 to 225°F)
Compensated Temp Range: 16 to 71°C (60 to 160°F)
Deflection: 0.025 to 0.076 mm (0.001 to 0.003")
Thermal Effects: Zero: ±0.029% FSO/C Span: ±0.036% FSO/C
Protection Class: P65

To Order (Specify Model Number)

<table>
<thead>
<tr>
<th>CAPACITY</th>
<th>MODEL NO.</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>LC304-25</td>
<td>$295</td>
</tr>
<tr>
<td>50</td>
<td>LC304-50</td>
<td>$295</td>
</tr>
<tr>
<td>75</td>
<td>LC304-75</td>
<td>$295</td>
</tr>
<tr>
<td>100</td>
<td>LC304-100</td>
<td>$295</td>
</tr>
<tr>
<td>200</td>
<td>LC304-200</td>
<td>$295</td>
</tr>
<tr>
<td>300</td>
<td>LC304-300</td>
<td>$295</td>
</tr>
<tr>
<td>500</td>
<td>LC304-500</td>
<td>$295</td>
</tr>
<tr>
<td>750</td>
<td>LC304-750</td>
<td>$295</td>
</tr>
<tr>
<td>1000</td>
<td>LC304-1000</td>
<td>$295</td>
</tr>
</tbody>
</table>

COMPATIBLE METERS:
- Series: DP41-S, DP23B-S

ACCESSORY
- OP-17 $15 Reference Book: Measure for Measure