A New Method for Automatic Reduction of Catenary Oscillations in Drum Hoist Installations

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Hoist configuration, Boliden Garpenberg mine, Sweden

- **Catenary length**: 25.3 m
- **Rope unit weight**: 6.05 kg/m
- **Distance from Head sheave to upper Level**: 14.5 m
- **Hoist drum diameter**: 4.0 m
- **Hoisting distance**: 1,042 m
- **Hoisting speed**: 8 m/s
- **Cage weight**: 4,500 kg
- **Payload range**: 0-4,000 kg

- **Riser**
- **Parallel section 'A'**
- **Crossover section**
- **Parallel section 'B'**
- **Crossover section**
- **Parallel section 'A'**

Symmetrical Lebus grooves
3 rope layers
Problem: Large Catenary oscillations occurred at certain combinations of speed, payload and cage position
Resonance: Problem solving

A comprehensive analysis and measurement program was carried out to find out when resonance occurs.
The following main tools were used for recording.

- ABB Argus high speed multi-channel data logger.
- 3-axis accelerometers connected to a PC.
- Video Cameras.

Main recorded signals:
- Hoisting speed
- Motor torque
- Cage position
- Load on head sheave
- Side forces on head sheave rim
- Vibration in the cage
- Vibration in head sheave foundation
The main reasons why it was possible to confirm that theory agreed with reality were:

- Measurement of load on head sheave bearing foundations from which the payload could be calculated.

- Measurement of catenary side forces on the head sheave rim. By being able to record these forces it was possible to determine when oscillation amplitudes started to build up.

- Large number of measurements at varying speed and load and direction of movement.

- Impact testing of catenary to verify that theoretically calculated frequencies were correct.
Symmetrical Lebus excitation Fourier coefficients

\[ v_{Ln} = \sum_{n=1}^{\infty} c_{vn} \cos(2\pi n N t) \]
\[ c_{zn} = \frac{c_{vn}}{2\pi n N} \]

**Velocity coefficients in mm/s at frequency (Cvn)**

<table>
<thead>
<tr>
<th>N</th>
<th>2N</th>
<th>3N</th>
<th>4N</th>
<th>5N</th>
<th>6N</th>
<th>7N</th>
<th>8N</th>
<th>9N</th>
<th>10N</th>
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<tbody>
<tr>
<td>0</td>
<td>-48</td>
<td>0</td>
<td>46</td>
<td>0</td>
<td>-43</td>
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<td>39</td>
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**Displacement coefficients in mm at frequency (Czn)**

<table>
<thead>
<tr>
<th>N</th>
<th>2N</th>
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<th>4N</th>
<th>5N</th>
<th>6N</th>
<th>7N</th>
<th>8N</th>
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<th>10N</th>
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<td>-1,8</td>
<td>0</td>
<td>1,2</td>
<td>0</td>
<td>-0,9</td>
</tr>
</tbody>
</table>

Symmetrical Lebus only generates frequencies with even multiples of N.

Asymmetrical Lebus generates frequencies with both odd and even multiples of N.

Asymmetrical Lebus should be avoided.
Catenary natural frequencies

\[ f_{ci} = \frac{i}{2L_c} \sqrt{\frac{F}{m}} \quad i = 1, 2, 3, \ldots \]

Where
- \( i \) = Mode number
- \( f_{ci} \) = frequency of the \( i \):th mode, Hz
- \( L_c \) = Catenary length, m
- \( F \) = Rope pull, N
- \( m \) = Rope unit weight, kg/m
Calculation of resonance frequencies at 8 m/s, payload 4000 kg

Figure 3. Resonances at payload 4000 kg, hoist speed 8 m/s
Calculation of resonance frequencies at 8 m/s, varying payload

Figure 4. Resonance points varying with payload, 8 m/s
Calculation of resonance frequencies at 3 m/s, empty cage

Figure 6. Resonances at 0 kg payload, 3 m/s
Measurement of catenary side forces on the head sheave rim

Figure 11. (Above)
8 m/s Down payload 3,100 kg. Note change of rope layers and acc/ret forces in payload signal - can be filtered out.

Figure 12. (Below)
8 m/s Down payload 3,100 kg. Close-up.
Load cells under head sheave bearing foundation plates
Control strategy

Calculate the theoretical resonance positions based on actual speed and payload.

In a zone before and after the resonance point, reduce the hoist speed.
Without Speed Reduction Zone (SRZ) at 8 m/s Down payload 3,100 kg.

Figure 11. (Above)
8 m/s Down payload 3,100 kg.
Without SRZ- control

Figure 12. (Below)
Close-up.
With SRZ control at 8 m/s Down payload 3,100 kg.

Figure 13. (Above)
8 m/s Down payload 3,100 kg.
With SRZ-control.

Figure 14. (Below)
Close-up.
Without and With SRZ control at 8 m/s Down payload 3,100 kg.

Figure 11. (Above) 8 m/s Down payload 3,100 kg. Without SRZ-control.

Figure 13. (Above) 8 m/s Down payload 3,100 kg. With SRZ-control.
Without and With SRZ control (Close-up) at 8 m/s Down 3,100 kg.

Figure 12. (Above) Without SRZ-control Close-up.

Figure 13. (Above) With SRZ-control. Close-up.
Resonance zone

Figure 18 Up- direction 8 m/s Up, Payload 2,100 kg without SRZ. Difference 21 m

Figure 19 Down- direction 8 m/s Down, Payload 2,100 kg without SRZ. Difference 137 m
Out of plane impact testing of rope

Verification of correctness of calculations, frequencies

Result: Very good accuracy.

<table>
<thead>
<tr>
<th>Transversal Resonances without Payload at Bottom Position</th>
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</thead>
<tbody>
<tr>
<td>n</td>
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<tr>
<td>----</td>
</tr>
<tr>
<td>Calculated Values</td>
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<tr>
<td>Measured Values</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transversal Resonances without Payload at Top Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
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Summary

• By accurately measuring the payload through head sheave foundation forces it is possible to forecast where in the shaft resonance will occur at any payload and hoisting speed.

• By measuring the catenary side forces on the head sheave rim it is possible to determine how long before and after the theoretical resonance point the hoisting speed has to be reduced (SRZ, speed reduction zone) to avoid large oscillation (rope whip) amplitudes.

• The SRZ can be programmed (preset values) based measurement during commissioning or in the future directly controlling the speed reduction from the side forces on the head sheave.
Recommendations:

- Head sheaves for drum hoists should have load cells under the sheave bearings for accurate measurement of the suspended load including the payload. The load cells can also be used for effective overload and slack rope protection as well as for chairing control.

- Catenary side forces should be measured to enable effective catenary oscillation control in all duty cases.

Result:

The presented method to calculate, detect and control the catenary oscillations has proven successful.