Modeling the torsional dynamics of reciprocating machines: “Pitfalls and Challenges”

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CRANK SHAFTS
TORSIONAL ANALYSIS: Modeling

Lumped-parameters model:

Moment of inertia per cylinder line includes contributions from reciprocating and rotating parts at the corresponding cylinder position.

Rotating parts: Crank pin, crank web, balance weight, connecting rod (lower part)

Recip parts: Piston, connecting rod (higher part)

Handbooks provide expressions to evaluate these concentrated moments of inertia for well-defined crankshaft geometries.

**FIGURE 5.1.** Sketch of the crankshaft: (a) actual system; (b) equivalent system, lumped-parameters model.
Crankthrow equivalent stiffness (Ke):

Observe that the crankpin is twisted while the crankweb is bended (Analytical method)

\[
\frac{1}{K_e} = \frac{L_e}{G_e I_e} = \frac{L_j}{G I_j} + \frac{L_c}{G I_c} + \frac{2}{K_w}.
\]
Inclusion of journal inertia and stiffness (FE modeling)
Hybrid model: Lumped and discretized system

“Case Example modelled in DyRoBeS”
1.25 Stiffness of driven machines

This section provides information and methods for assessing the point of rigidity, equivalent length and stiffness of driven-machine shafts.

Numerical values of stiffness of various types of Heenan & Froude dynamometer shafts are given together with the corresponding values for moments of inertia in section 1.15 (pp. 33 and 34).

1.251 Point of rigidity of armatures and other driven machines

As previously stated on p. 52, the ‘point of rigidity’ of a shaft is defined as the point at which the moment of inertia of a distributed mass (such as that of an armature core) is concentrated.

Although the stiffening effect of a mass on the shaft upon which it is mounted is gradual along most of the shaft length, for simplicity of calculation it is assumed (a) that no stiffening effect is felt by the shaft supporting the mass up to a certain point on the shaft axis, viz. the point of rigidity, and (b) that the shaft ends at this point (and becomes ‘infinitely rigid’ beyond it).
The following information in regard to points of rigidity of shaft portions supporting an armature core is based on vibration tests of pairs of identical generators coupled back-to-back, which were carried out by B.I.C.E.R.A.

Plain keyed shafts (Fig. 1)

Point of rigidity is situated at two-thirds of the distance from the beginning of the armature core to the centre of gravity of the armature (including commutator).

Shafts with solid cruciform cross-section (Fig. 2)

Point of rigidity at two-thirds of the distance from the beginning of the armature core to the centre of gravity of the cross-section (including commutator).
Shaft with press fit or shrunk fit spiders (Fig. 3)

Point of rigidity at one-third of the distance from the beginning of the armature core to the centre of gravity of the armature (including commutator).

Fig. 3.

Fig. 4.

(a) Original system. (b) Equivalent system.

Fig. 5.
Typical reported **Data for torsion analysis**

<table>
<thead>
<tr>
<th>Description</th>
<th>mass no.</th>
<th>Inertia I kgm²</th>
<th>Stiffness K MNm/rad</th>
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<tbody>
<tr>
<td>CRANK1</td>
<td>1</td>
<td>97.00</td>
<td>210.56</td>
</tr>
<tr>
<td>CRANK2</td>
<td>2</td>
<td>81.15</td>
<td>83.62</td>
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<tr>
<td>CRANK3</td>
<td>3</td>
<td>101.40</td>
<td>210.41</td>
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<tr>
<td>CRANK4</td>
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<td>79.00</td>
<td>194.44</td>
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<tr>
<td>FLYWHEEL</td>
<td>5</td>
<td>2414.15</td>
<td>491.59</td>
</tr>
<tr>
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<td>6</td>
<td>2643.60</td>
<td>1150.80</td>
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<tr>
<td>LAMINATIONS</td>
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<td>2495.69</td>
<td>40.99</td>
</tr>
<tr>
<td>EXT. FAN</td>
<td>8</td>
<td>61.42</td>
<td>-</td>
</tr>
</tbody>
</table>
CASE1: GIVEN "JP 4 CYLINDERS"
## Reported results

<table>
<thead>
<tr>
<th>Node</th>
<th>System natural torsional frequency</th>
<th>Margins from</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cycles/ min.</td>
<td>Operating speed</td>
<td>Power frequency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 times</td>
<td>margins/multiple</td>
<td>1 times</td>
</tr>
<tr>
<td>1</td>
<td>4043</td>
<td>-</td>
<td>8.7% / 10</td>
<td>34.8%</td>
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<tr>
<td>2</td>
<td>5304</td>
<td>-</td>
<td>42.6% / 10</td>
<td>76.8%</td>
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<tr>
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<td>7812</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>&gt;15000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Large margins (>100%) are not presented in this table and are indicated with -.

**Operating speed driver:** 372 RPM

**Operating speed compressor:** 372 RPM

**Electrical power frequency:** 50 Hz (3000 CPM)
CASE 1: GIVEN "JP 4 CYLINDERS"
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CASE1: GIVEN ”JP 4 CYLINDERS”
CASE2: GIVEN "RECIPI MASS"
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CASE2: GIVEN "RECIP MASS"

Torsional Vibration Mode Shape
Mode No. = 2, Undamped Frequency = 6149 cpm; 102.49 Hz
CASE2: GIVEN "RECIP MASS"
HB has started partnership with AVL (Excite & Fire)

Analysis Targets:
- Shaft Vibrations
- Base frame vibrations
- Acoustics
  - structure borne noise
  - air borne noise
- Component strength

Angular Displacement
Magnitude (Mean-to-Peak Value)
AVL excite + Ansys/Abaqus: Stress analysis

Fillet Modeler – automated mesh generation for crankshaft durability analysis