HYDRODYNAMIC LUBRICATION

ILLUSTRATION: JOURNAL BEARING CFD

A CFD template for a journal bearing is

$$P_P = \frac{(A\ P_E + B\ P_W + C\ P_N + D\ P_S + H)}{(A + B + C + D)}$$

$$A = [(h_E+h_P)/2]^3\ /\ [\Delta x^2] \qquad B = [(h_W+h_P)/2]^3\ /\ [\Delta x^2]$$

$$C = [(h_N+h_P)/2]^3\ /\ [\Delta y^2] \qquad D = [(h_S+h_P)/2]^3\ /\ [\Delta y^2]$$

$$H = -\ 6\mu\ S\ (h_E-h_W)/[2\Delta x]$$

Consider a case where the rolled out geometry is 0.12m long and 0.04m wide. For a 9 point CFD grid this gives Δx equal to 0.12/4 or 0.03m and Δy equal to 0.4/4 or 0.01m. The rolled out length is πR. Working back one finds that R is 0.038m. Let the speed S due to shaft rotation be 5m/s. This speed is R 2π RPM/60. Working back one finds that RPM is 1256. Let the maximum gap be 1.0mm and the minimum gap be 0.2mm. Assume a linear gap variation from the maximum to the minimum. Let the oil viscosity μ be 0.1 Ns/m^2.

The CFD coefficients for point #1 are

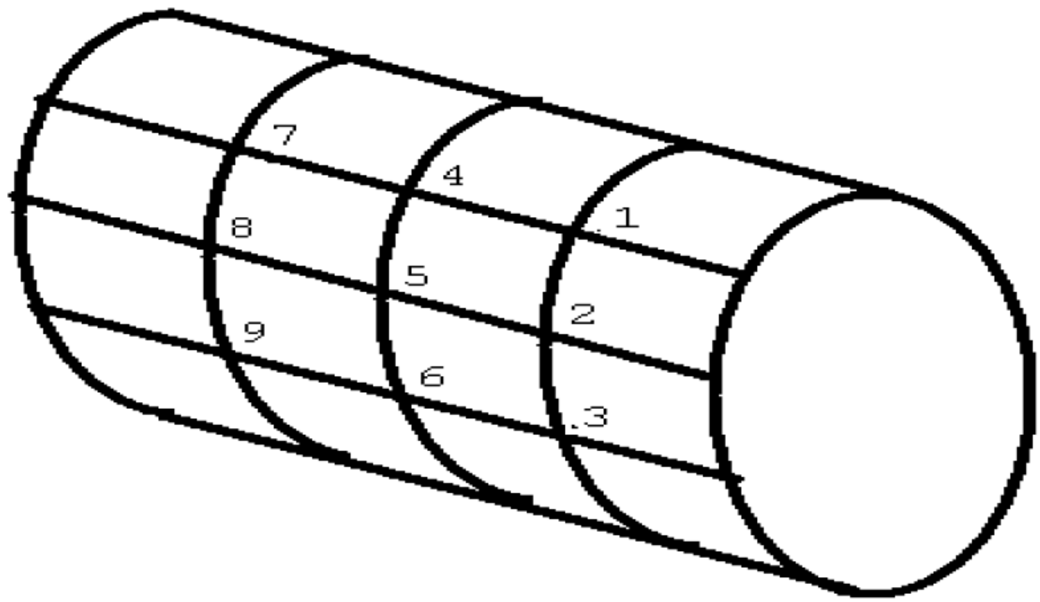
$$A = (0.7 \times 10^{-3})^3/(0.03)^2 = 3.851 \times 10^{-7}$$

$$B = (0.9 \times 10^{-3})^3/(0.03)^2 = 8.184 \times 10^{-7}$$

$$C = (0.8 \times 10^{-3})^3/(0.01)^2 = 5.120 \times 10^{-6}$$

$$D = (0.8 \times 10^{-3})^3/(0.01)^2 = 5.120 \times 10^{-6}$$

$$H = -\ [6*0.1*5*(0.6-1.0)\times10^{-3}]/[2*0.03] = 0.0201$$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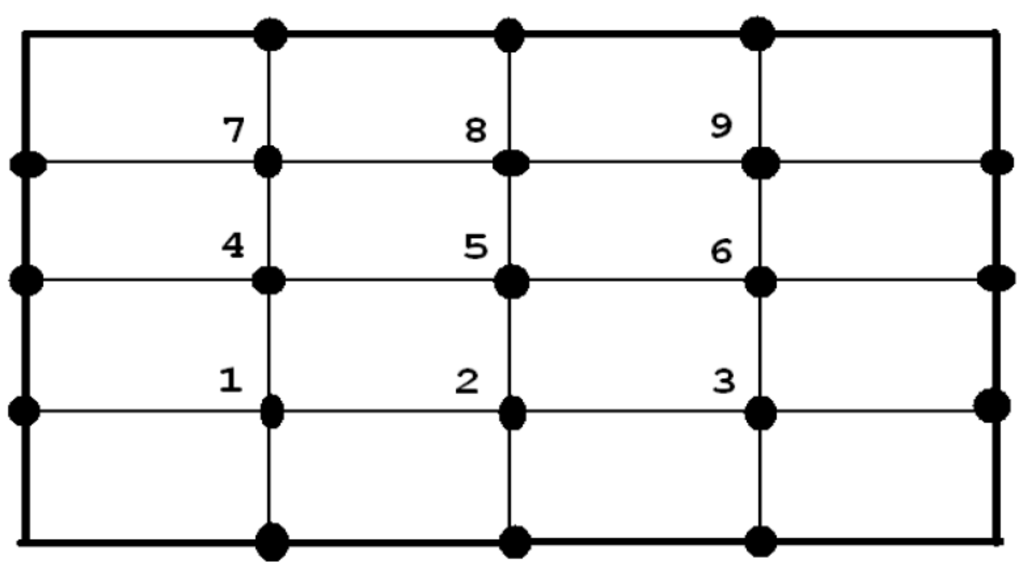
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The CFD coefficients for point #2 are

$$A = (0.5 \times 10^{-3})^3/(0.03)^2 = 1.403 \times 10^{-7}$$

$$B = (0.7 \times 10^{-3})^3/(0.03)^2 = 3.851 \times 10^{-7}$$

$$C = (0.6 \times 10^{-3})^3/(0.01)^2 = 2.160 \times 10^{-6}$$

$$D = (0.6 \times 10^{-3})^3/(0.01)^2 = 2.160 \times 10^{-6}$$

$$H = -\ [6*0.1*5*(0.4-0.8)\text{x}10^{-3}]/[2*0.03] = 0.0201$$

The CFD coefficients for point #3 are

$$A = (0.3 \times 10^{-3})^3/(0.03)^2 = 0.3031 \times 10^{-7}$$

$$B = (0.5 \times 10^{-3})^3/(0.03)^2 = 1.403 \times 10^{-7}$$

$$C = (0.4 \times 10^{-3})^3/(0.01)^2 = 0.640 \times 10^{-6}$$

$$D = (0.4 \times 10^{-3})^3/(0.01)^2 = 0.640 \times 10^{-6}$$

$$H = -\ [6*0.1*5*(0.2-0.6)\text{x}10^{-3}]/[2*0.03] = 0.0201$$

Points 4 and 7 have the same coefficients as point 1. Points 5 and 8 have the same coefficients as point 2. Points 6 and 9 have the same coefficients as point 3. The CFD template gives

$$P_1 = \frac{0.3851\ P_2 + 5.12\ P_4 + 0.0201 \times 10^{+6}}{0.3851 + 0.8184 + 5.12 + 5.12}$$

$$= 0.0337\ P_2 + 0.4474\ P_4 + 1757$$

$$P_2 = \frac{0.1403\ P_3 + 0.3851\ P_1 + 2.16\ P_5 + 0.0201 \times 10^{+6}}{0.1403 + 0.3851 + 2.16 + 2.16}$$

$$= 0.029\ P_3 + 0.0795\ P_1 + 0.4458\ P_5 + 4149$$

$$P_3 = \frac{0.1403\ P_2 + 0.64\ P_6 + 0.0201 \times 10^{+6}}{0.03031 + 0.1403 + 0.64 + 0.64}$$

$$= 0.0967\ P_2 + 0.4412\ P_6 + 13859$$

$$P_4 = \frac{0.3851\ P_5 + 5.12\ P_7 + 5.12\ P_1 + 0.0201 \times 10^{+6}}{0.3851 + 0.8184 + 5.12 + 5.12}$$

$$= 0.0337\ P_5 + 0.4474\ P_7 + 0.4474\ P_1 + 1757$$

$$P_5 = \frac{0.1403\ P_6 + 0.3851\ P_4 + 2.16\ P_8 + 2.16\ P_2 + 0.0201 \times 10^{+6}}{0.1403 + 0.3851 + 2.16 + 2.16}$$

$$= 0.029\ P_6 + 0.0795\ P_4 + 0.4458\ P_8 + 0.4458\ P_2 + 4149$$

$$P_6 = \frac{0.1403\ P_5 + 0.64\ P_9 + 0.64\ P_3 + 0.0201 \times 10^{+6}}{0.03031 + 0.1403 + 0.64 + 0.64}$$

$$= 0.0967\ P_5 + 0.4412\ P_9 + 0.4412\ P_3 + 13859$$

$$P_7 = \frac{0.3851\ P_8 + 5.12\ P_4 + 0.0201 \times 10^{+6}}{0.3851 + 0.8184 + 5.12 + 5.12}$$

$$= 0.0337\ P_8 + 0.4474\ P_4 + 1757$$

$$P_8 = \frac{0.1403\ P_9 + 0.3851\ P_7 + 2.16\ P_5 + 0.0201 \times 10^{+6}}{0.1403 + 0.3851 + 2.16 + 2.16}$$

$$= 0.029\ P_9 + 0.0795\ P_7 + 0.4458\ P_5 + 4149$$

$$P_9 = \frac{0.1403\ P_8 + 0.64\ P_6 + 0.0201 \times 10^{+6}}{0.03031 + 0.1403 + 0.64 + 0.64}$$

$$= 0.0967\ P_8 + 0.4412\ P_6 + 13859$$

The equations for pressure can be solved using Gauss Seidel iteration. The iteration starts with all pressures set to zero. The first sweep through the equations gives:

$$P_1 = 0.0337\ P_2 + 0.4474\ P_4 + 1757$$
$$= 0 + 0 + 1757 = 1757$$

$$P_2 = 0.029\ P_3 + 0.0795\ P_1 + 0.4458\ P_5 + 4149$$
$$= 0 + 0.0795 * 1757 + 0 + 4149 = 4289$$

$$P_3 = 0.0967\ P_2 + 0.4412\ P_6 + 13859$$
$$= 0.0967 * 4289 + 0 + 13859 = 14274$$

$$P_4 = 0.0337\ P_5 + 0.4474\ P_7 + 0.4474\ P_1 + 1757$$
$$= 0 + 0 + 0.4474 * 1757 + 1757 = 2543$$

$$P_5 = 0.029\ P_6 + 0.0795\ P_4 + 0.4458\ P_8 + 0.4458\ P_2 + 4149$$
$$= 0 + 0.078 * 2543 + 0 + 0.4458 * 4289 + 4149 = 6263$$

$$P_6 = 0.0967\ P_5 + 0.4412\ P_9 + 0.4412\ P_3 + 13859$$
$$= 0.0967 * 6263 + 0 + 0.4412 * 14274 + 13859 = 20762$$

$$P_7 = 0.0337\ P_8 + 0.4474\ P_4 + 1757$$
$$= 0 + 0.4474 * 2543 + 1757 = 2895$$

$$P_8 = 0.029\ P_9 + 0.0795\ P_7 + 0.4458\ P_5 + 4149$$
$$= 0 + 0.0795 * 2895 + 0.4458 * 6263 + 4149 = 7171$$

$$P_9 = 0.0967\ P_8 + 0.4412\ P_6 + 13859$$
$$= 0.0967 * 7171 + 0.4412 * 20762 + 13859 = 23712$$

After 100 sweeps through the equations one gets

$P_1 = 5483$ $P_2 = 13866$ $P_3 = 36191$

$P_4 = 7284$ $P_5 = 18468$ $P_6 = 47519$

$P_7 = 5483$ $P_8 = 13866$ $P_9 = 36191$

The cell area is $\Delta x\ \Delta y = 0.03*0.01 = 0.0003$.

The incremental loads $\Delta F = P\ \Delta x\ \Delta y$ are

$\Delta F_1 = 1.64$ $\Delta F_2 = 4.14$ $\Delta F_3 = 10.80$

$\Delta F_4 = 2.17$ $\Delta F_5 = 5.51$ $\Delta F_6 = 14.20$

$\Delta F_7 = 1.64$ $\Delta F_8 = 4.14$ $\Delta F_9 = 10.80$

The horizontal components $\Delta F_H = \Delta F\ \mathrm{Sin}\theta$ are

$\Delta F_{1H} = +1.16$ $\Delta F_{2H} = +4.14$ $\Delta F_{3H} = +7.64$

$\Delta F_{4H} = +1.54$ $\Delta F_{5H} = +5.51$ $\Delta F_{6H} = +10.04$

$\Delta F_{7H} = +1.16$ $\Delta F_{8H} = +4.14$ $\Delta F_{9H} = +7.64$

The vertical components $\Delta F_V = \Delta F\ \mathrm{Cos}\theta$ are

$\Delta F_{1V} = -1.16$ $\Delta F_{2V} = 0.0$ $\Delta F_{3V} = +7.64$

$\Delta F_{4V} = -1.54$ $\Delta F_{5V} = 0.0$ $\Delta F_{6V} = +10.04$

$\Delta F_{7V} = -1.16$ $\Delta F_{8V} = 0.0$ $\Delta F_{9V} = +7.64$

The total loads are

$$F_H = \sum \Delta F_H = +42.96 \qquad F_V = \sum \Delta F_V = +21.46$$

$$F = \sqrt{[F_H * F_H + F_V * F_V]} = 48.02$$

The load angle $\theta = \tan^{-1} [F_H / F_V] = 63.4°$