Calculation of Piston Side Load on Sanderson Pumps and Compressors

Albert E. Sanderson, Ph.D.
Vice President of R&D
Sanderson Engine Development, LLC
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The piston side load of the Sanderson Mechanism has been under discussion recently, and some engineers have been questioning whether our piston joint, called the "zero side load" (ZSL) joint, really is literally zero as claimed. This paper is intended to show that to be actually the case, based on the geometry of the ZSL joint.

The motion of the piston within the cylinder is a straight line, guided by two supporting members that may either be two pistons in a double configuration, or a piston and a guide rod in a single piston configuration. The primary force from the piston drive pin in the transition arm through a ZSL joint is directed along this line, so the driving force has no component at right angles to the cylinder axis. It is obvious that side forces cannot be generated in this manner. Other types of side forces are calculated for comparison.

Standard Calculation of Geometric Side Force (ref: Heywood, p 732)

$$F_t = F_p \tan\phi = \{ -ma + (\pi B^2 /4)\, p \pm F_f \} \tan\phi$$

Where
- F_t is the side force (thrust) of the piston head on the cylinder,
- F_p is the instantaneous force on the piston,
- ϕ is the angle between the connecting rod and the cylinder axis,
- m is the mass of the piston, say 0.25 lb,
- a is the acceleration of the piston, say 32 g's,
- B is the bore diameter of the cylinder, say 2 inches,
- p is the pressure on the piston head, say 60 psi, and
- F_f is the frictional force on the piston assembly, say 4 lb.

The three terms within the brackets are inertial forces, cylinder pressure forces, and frictional forces. All the quantities within the brackets can be calculated, and with the given typical values we get

$$F_t = \{ -8 + 188 \pm 4 \} \tan\phi = 200 \tan\phi \quad \text{lbs, worst case, all terms adding.}$$

Apply this equation to three piston drives, the crankshaft, the wobble plate and the Sanderson mechanism:

1. Piston side load for a crankshaft mechanism.
The rod to crank ratio of typical pumps is 3 to 1 so $\tan\phi$ is 1/3, and

$$F_t = 67 \text{ lbs.}$$

2. Piston side load for a wobble plate mechanism.
The wobble angle of a typical pump is ± 15º, and the maximum deviation of the connecting rod can occur at 0 degrees, or midstroke of the piston. At that point the deviation, d, from straight line of the connecting rod is

$$d = R \{ 1 - \cos 15^\circ \} = 0.034 R$$

the connecting rod length, L, can be the same length as the radius R of the wobble plate, so that R/L = 1, and

$\tan \phi = 0.034$ R/L = 0.034, and

$F_t = 6.8$ lbs.

3. Piston side load for the Sanderson mechanism.
Since the angle ϕ is identically zero at all points in the piston cycle, side load is also identically zero.

$F_t = 0.0$ lb.

This is the customary way of calculating side load, other sources of side load are normally present but are never considered because they are essentially negligible by comparison to geometric side loads. Other sources are:

Side load from friction.

The frictional side load of sliding parts within the ZSL joint of the Sanderson mechanism contributes side load. The pillow blocks of a ZSL piston joint slide and generate a force that is normal to the piston axis. This force is in the right direction to create side load, but is of negligible magnitude. We can calculate this force if we estimate the coefficient of friction μ of a hydrodynamically lubricated surface to be on the order of 0.0005,

$F_t = \mu F_p = 0.0005 \times 200 = 0.1$ lb.

The side force from this cause is thus only 0.05% of the force required to drive the piston, which is totally negligible from a practical point of view. None of the methods of calculating side force that I have ever seen even mentions this source of side load for the crank or wobble plate mechanism, although if it were to be calculated, it would undoubtedly be many times larger than the amount shown.

Side load from gravity.

Another possibility but never mentioned source of side load on the piston is the effect of gravity. Since this depends on the orientation of the cylinders with respect to gravity, it could be zero. But in the worst case, if the cylinders lie horizontally in all three cases above, we would have simply,

$F_t = mg = 0.25 \times 1 = 0.25$ lb.

Again, this quantity is quite small compared to the crank or wobble plate side forces, and is normally neglected.

Conclusion:

In the future when this question is raised, we can simply state that our geometric side load is literally zero, and obviate the need to get into discussions about friction, coefficients of friction, sliding parts, and gravity. We have shown that the side forces of crank or wobble plate mechanisms are orders of magnitude greater than those of the Sanderson mechanism, even when we include normally neglected fringe effects.

Ref: "Internal Combustion Engine Fundamentals", John B. Heywood, McGraw-Hill, 1988.