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ANALYSIS FOR DEVELOPMENT OF THE ANTI-ROTATIONAL ROLLER CLUTCH DEVICE FOR SCROLL COMPRESSORS

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ABSTRACT

This report describes the analysis for the development of the anti-rotational roller clutch device for scroll compressors. The anti-rotational device was designed to prevent reversing of the orbiting scroll and the drive shaft due to scroll compressor shutdown. The force analysis of the roller clutch is presented for different engaged positions of the rollers during compressor shutdown. As a result of the preliminary analysis, a spring design is proposed to support the clutch assembly.

NOMENCLATURE

R	*Crankcase Radius*
r	*Roller Radius*
T	*Gas Torque for Reverse Rotation*
α	*Roller Wedge Angle*
F_{h1}, F_{h2}	*Normal Force Between Hub and Roller*
F_{hf1}, F_{hf2}	*Friction Force Between Hub and Roller*
F_{c1}, F_{c2}	*Normal Force Between Roller and Counterweight*
F_{cf1}, F_{cf2}	*Friction Force Between Roller and Counterweight*
F_s	*Shaft Drive Force on Counterweight*
L_s	*Distance from F_s to Counterweight X-axis*
L_v	*Distance from F_{c1} to Counterweight X-axis*
L_h	*Distance from F_{c1} to Counterweight Y-axis*
D_{x1}, D_{x2}	*Distance from Center of Rollers to Counterweight X-axis*
α_{x1}, α_{x2}	*Angle Between Hub X-axis and Roller, Hub Center Connection Line*
L_f	*Offset Between Counterweight Center and Hub Center*
M_c	*Overturning Moment of Counterweight*
F_c	*Unsymmetrical Force from (F_{c1} - F_{c2}) or (F_{cf1} - F_{cf2})*
F_{s1}	*Spring Preload for Supporting Counterweight*
L_{s1}	*Distance from F_{s1} to Pivot Point O*
F_{s2}	*Spring Force for Counteract Moment M_c*
L_{s2}	*Distance from F_{s2} to Pivot Point O*

INTRODUCTION

When scroll compressors shutdown, the gas in the pressurized pockets and backflow of compressed gas from the discharge pocket cause a reverse orbit of the orbiting scroll and rotation of the drive shaft. The reverse rotation can generate unacceptable noise during compressor shutdown.

The anti-rotational roller clutch device was designed to prevent the reverse rotation of the scroll compressor. The configuration of the roller clutch device is shown in Figures 1, 2 and 3. The upper counterweight has a bore with two parallel drive flats which match the two drive flats on the shaft. The counterweight also has two slots as shown in Figure 2. The roller wedge angle, α in Figure 3, between the back surface of the slot and the vertical, is designed so that the two rollers are wedged between the crankcase hub and the counterweight during compressor shutdown. The friction forces between the rollers, counterweight and crankcase hub will stop the reverse rotation of the counterweight/shaft assembly. Furthermore, the centrifugal force during compressor startup frees the rollers and allows the counterweight and the shaft to rotate in the forward direction. The rollers remain disengaged during steady state. Figure 2 shows the positions of the rollers during compressor startup, steady state and lockup.

In this paper, the force analysis of the roller clutch is presented for different engaged positions of the rollers during compressor shutdown. The offset between the counterweight and the hub at lockup is significant because it results in an overturning moment Mc on the counterweight. As a result of the preliminary analysis, a spring design is proposed to support the counterweight and create a restoring moment.

FORCE ANALYSIS

Layout for Engaged Position of Rollers

One of the difficulties for the roller clutch design is the randomness of the rollers in the engaged positions during compressor shutdown. As long as the engaged positions of the rollers are offset from the counterweight X-axis, the counterweight centerline will be offset from the crankcase centerline. Figure 3 shows the counterweight in one possible offset position relative to the crankcase hub.

It is also important to note that the rollers can tilt at the engaged position which further complicates the force analysis.

Force Analysis during Compressor Shutdown

Three cases of force analyses are discussed in this section. They are force analyses with the counterweight aligned with the crankcase hub, offset from the crankcase hub, and with the rollers tilted.

a. Counterweight Aligned with Crankcase Hub

The forces on the crankcase hub are shown in Figure 4(a). F_{h1} and F_{h2} are the normal forces from the rollers and F_{hf1} and F_{hf2} are the friction forces between the roller surfaces and the hub surface. The torque required to prevent reverse rotation of the shaft may be written as

$$T = F_{hf1}R + F_{hf2}R. \quad (1)$$

Here, R is the outer radius of the crankcase hub. Because the counterweight center is coincident with the hub center, the forces on the hub and the counterweight are symmetric. That means $F_{hf1} = F_{hf2}$.

Figure 4(b) shows the force diagrams for both rollers. Here, F_{cf1} and F_{cf2} are the friction forces between the roller surfaces and the back faces of the counterweight slots. F_{c1} and F_{c2} are the normal forces between the counterweight and the rollers. The moment and the force balance equations are given as

$$\sum M = 0 = F_{hf1}\, r - F_{cf1}\, r \quad (2)$$

$$\sum F_y = 0 = F_{cf1}\cos(\alpha) - F_{c1}\sin(\alpha) + F_{hf1} = 0, \quad (3)$$

and

$$\sum F_x = 0 = F_{cf1}\sin(\alpha) + F_{c1}\cos(\alpha) - F_{h1} = 0. \quad (4)$$

From equations (2), (3) and (4) the resultant forces are

$$F_{c1} = F_{hf1}\,[1 + \cos(\alpha)]/\sin(\alpha), \quad (5)$$

$$F_{h1} = F_{c1} \quad (6)$$

and

$$F_{hf1} = F_{cf1} \quad (7)$$

in which, r is the roller radius and angle α is the roller wedge angle.

From the force diagram of the counterweight shown in Figure 4(c), the force equations are given as

$$F_{c1} = F_{c2} \quad \text{and} \quad F_{cf1} = F_{cf2}. \quad (8)$$

Therefore, the moment equation may be written as

$$2 F_s L_s = -2 [F_{cf1} \cos(\alpha) - F_{c1} \sin(\alpha)] L_h - 2 [F_{cf1} \sin(\alpha) + F_{c1} \cos(\alpha)] L_v, \qquad (9)$$

in which L_h and L_v are the distances from the roller contact point to the counterweight x and y axes. L_s is the distance between F_s, the shaft drive force, and the counterweight x-axis. F_s may be calculated from equation (9).

Counterweight Offset from Crankcase Hub

If the engaged positions of the rollers are offset from the counterweight x-axis, the counterweight centerline will be offset from the crankcase centerline. The offset between the counterweight centerline and the crankcase centerline is denoted as L_f. The distances D_{x1} and D_{x2} shown in Figure 3 are from the centers of the rollers to the counterweight x-axis. The angles α_{x1} and α_{x2} are the angles from the horizontal axis to the line connecting the roller centerline to the crankcase centerline.

The forces for the hub and the rollers are shown in Figures 5(a) and 5(b). The moment and the force balance equations are given as

$$F_{hf1}\, r - F_{cf1}\, r = 0, \qquad (10)$$

$$F_{c1} \cos(\alpha - \alpha_{x1}) + F_{cf1} \sin(\alpha - \alpha_{x1}) - F_{h1} = 0 \qquad (11)$$

and

$$F_{cf1} \cos(\alpha - \alpha_{x1}) - F_{c1} \sin(\alpha - \alpha_{x1}) + F_{hf1} = 0. \qquad (12)$$

The above assumes the friction coefficients at the roller/crankcase and roller/counterweight interfaces are identical. From equations (10), (11) and (12), the forces for roller 1 are calculated as

$$F_{c1} = F_{h1} = F_{hf1} [1 + \cos(\alpha - \alpha_{x1})]/\sin(\alpha - \alpha_{x1}). \qquad (13)$$

Similarly, the forces for roller 2 may be expressed as

$$F_{c2} = F_{h2} = F_{hf2} [1 + \cos(\alpha - \alpha_{x2})]/\sin(\alpha - \alpha_{x2}). \qquad (14)$$

Equations (13) and (14) indicate two significant results when compared with (5) and (6) for the aligned condition. First,

$$F_{c1} \neq F_{c2} .$$

Second, the magnitudes of F_{c1} and F_{c2}, the roller normal forces, may increase substantially in the offset case. Also, note from Figure 5(a) that $\alpha_{x1} \neq \alpha_{x2}$

Figure 5(c) shows the force diagram for the counterweight during compressor shutdown in which F_s is the shaft drive force. It is observed that the counterweight will be balanced only when it aligns with the crankcase hub. Any amount of crankcase/counterweight offset will introduce the unbalanced force (F_{c1} - F_{c2}) or (F_{cf1} - F_{cf2}) on the counterweight. The unbalanced force, F_s, will generate a moment, M_c, to rotate the counterweight until it locates two contact points on the shaft. To overcome this, the counterweight needs a support spring to counteract the moment Mc.

Roller Tilt in Engaged Position

If either one of the rollers tilts in the engaged position during compressor shutdown, this will also contribute to the moment unbalance, M_c.

Counterweight Support Design

The previous analyses show that overcoming the overturning moment M_c on the counterweight is very critical for to insure counterweight stability. A coil spring, as shown in Figure 1, can be effectively used to counteract M_c.

The force diagram for the counterweight and the spring is shown in Figure 6, in which F_{s1} is the spring preload and F_{s2} is the spring force which counteracts the overturning moment M_c. L_{s1} and L_{s2} are distances from F_{s1} and F_{s2} to the point O which is assumed as a pivot point for the counterweight under the moment M_c. The moment balance equation for the counterweight may be given as

$$\sum M = 0 = M_c - F_{s1} L_{s1} - F_{s2} L_{s2} = 0 \qquad (15)$$

To overcome the overturning moment M_c the spring needs to be designed so that

$$F_{s1} L_{s1} + F_{s2} L_{s2} \geq M_c. \qquad (16)$$

However, the preload of the spring should not be too large to lose the compliance between the counterweight and the shaft.

CONCLUSIONS

Since it is unrealistic to expect the crankcase and the counterweight to stop in the aligned position, it is necessary to design a support for the roller clutch that will counteract the moment M_c resulting from the counterweight force unbalance. A spring support can provide the necessary restoring moment.

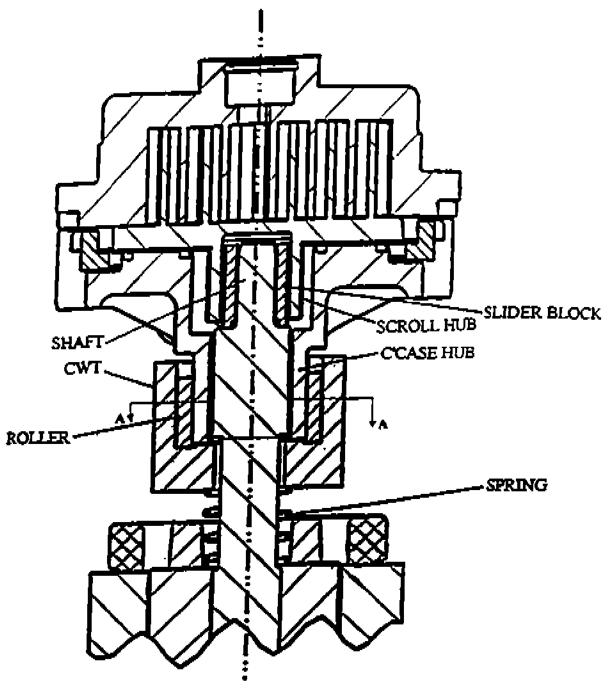


Figure 1 Scroll Compressor Assembly Layout with Anti-rotational Roller Clutch Device

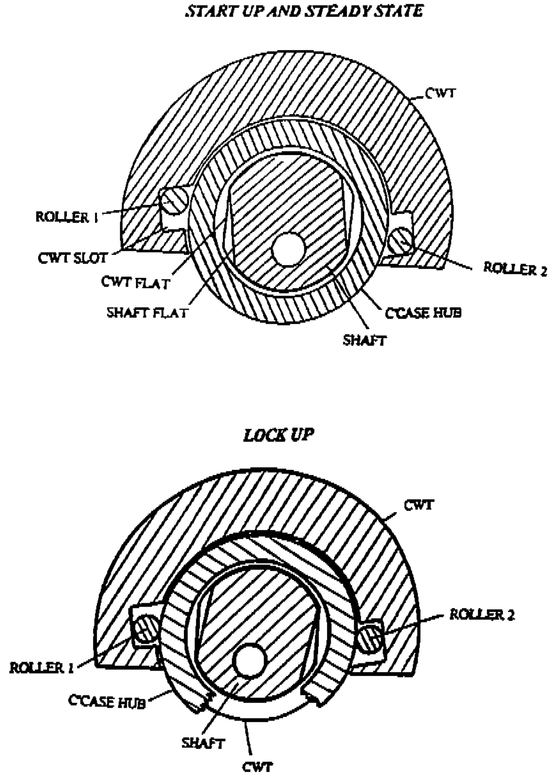


Figure 2 Roller Clutch at Start-up, Steady State and Lock-up Position (Section A-A from Figure 1)

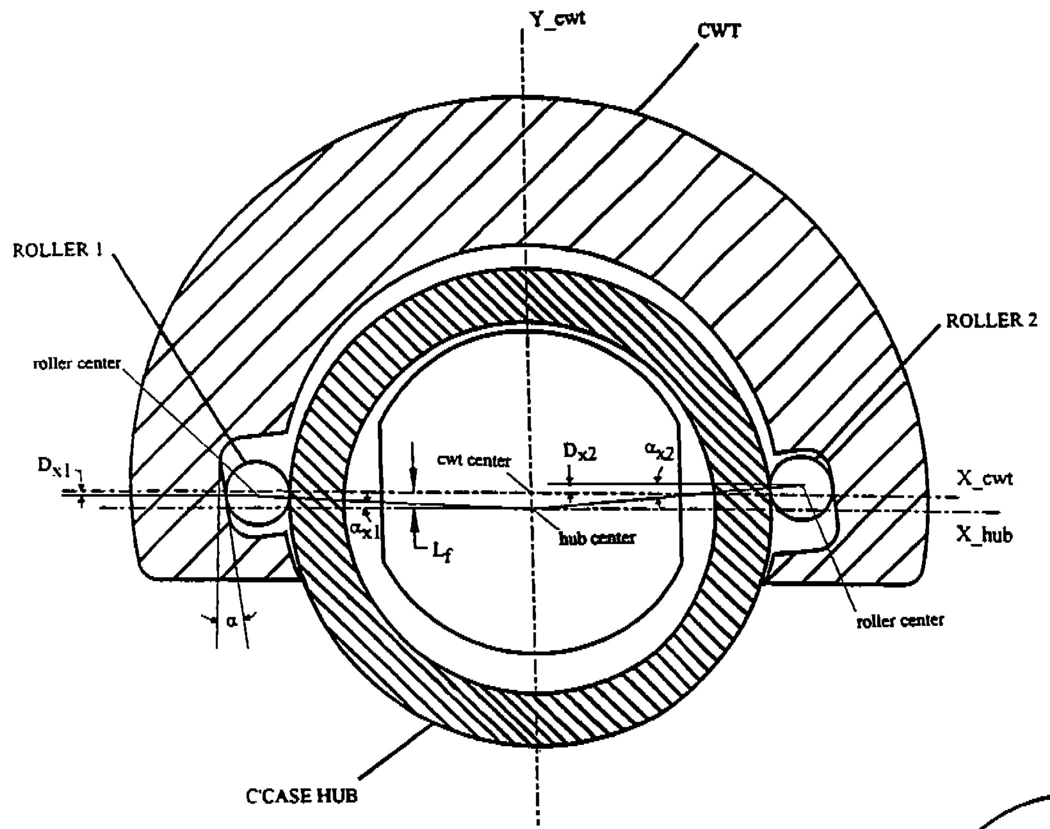
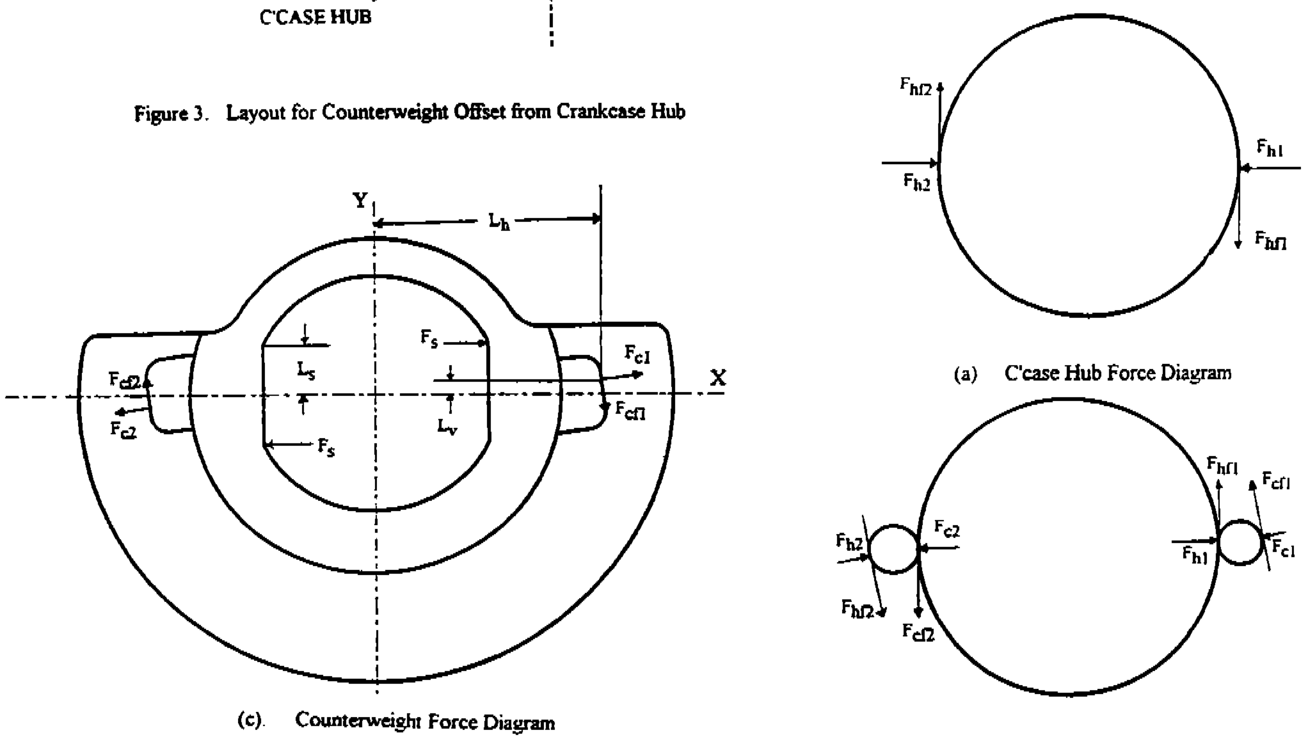


Figure 3. Layout for Counterweight Offset from Crankcase Hub

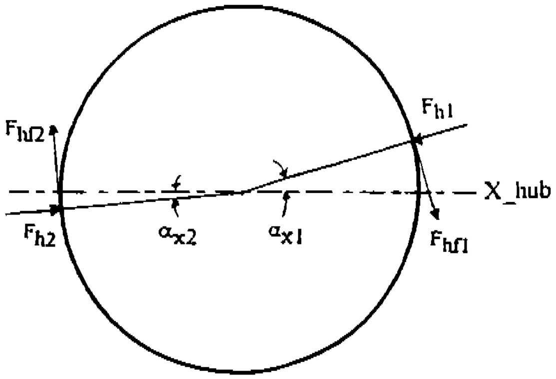


(c). Counterweight Force Diagram

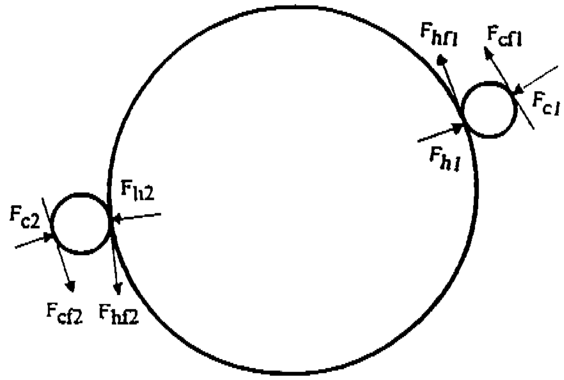
(a) C'case Hub Force Diagram

(b). Rollers Force Diagram

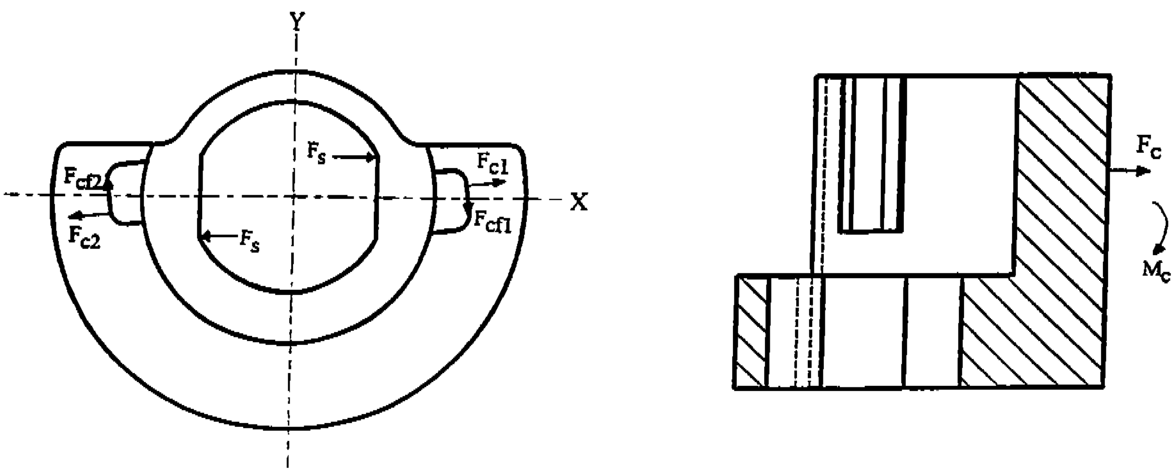
Figure 4. Force Diagrams for Counterweight and C'case Hub at Same Center



(a). C'case Hub Force Diagram



(b). Rollers Force Diagram



(c). Counterweight Force Diagram

Figure 5 Force Diagrams for Counterweight offset from C'case Hub

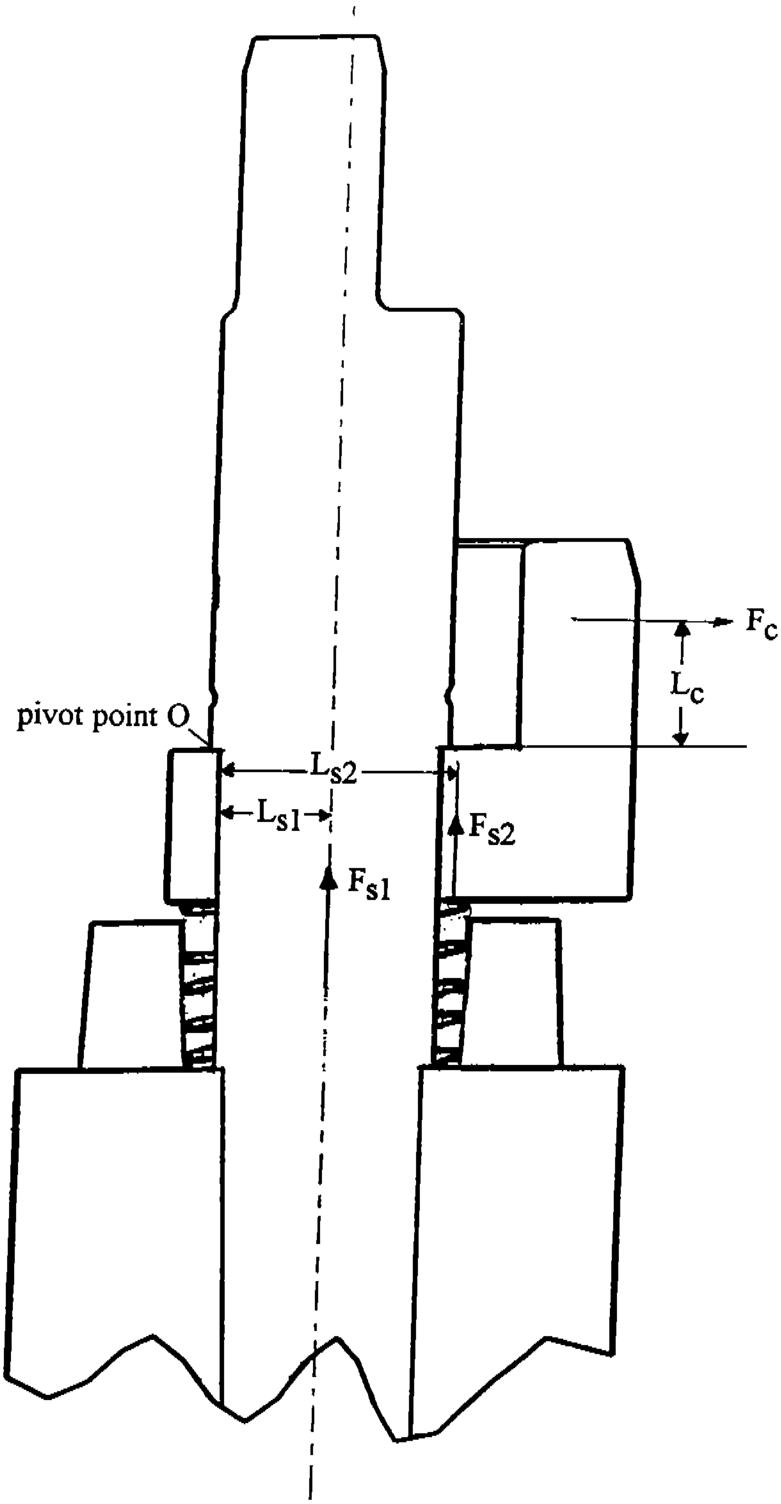


Figure 6. Counterweight Support Design