Chapter 5
Laws Governing Surface Contact

5.1 Necessity of Surface Contact Laws

To apply knowledge obtained about the bit's geometrical changes, it is necessary to have a general understanding of the laws that govern surface contact. As discussed in section 1.3 a primary reason for bit failure is the inability of the user to overcome the axial cam-out force, which increases with bit wear. In this chapter, the surface contact laws that link geometry to force transfer, will be explained.

5.2 Fundamental Laws Governing Surface Contact

To apply the laws of surface contact, the interacting surfaces must be assumed to be smooth and continuous. It is additionally assumed that the surface contact occurs at a single point (Fig. 5.1) [Mabie & Reinholtz]. For the Phillips bit application, symmetrical contact of each of the four wings is assumed (Fig. 5.2).

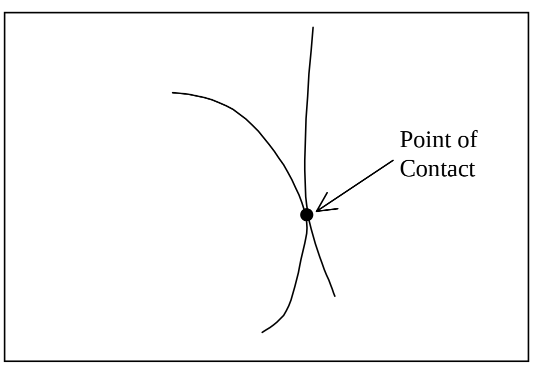

Figure 5.1
Single Point Contact between Surfaces

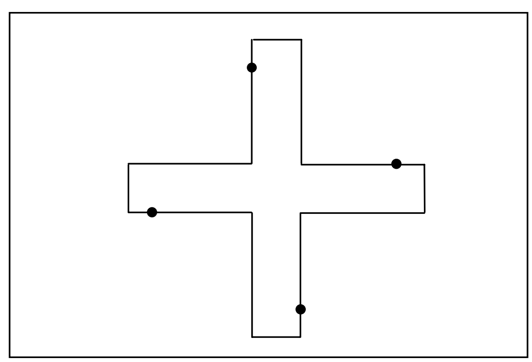

Figure 5.2
Symmetrical Contact of Bit

There are three laws governing surface contact [Shooter, West & Reinholtz]:

1) At the point of contact, both a common tangent and common normal exist (See Fig. 5.3).

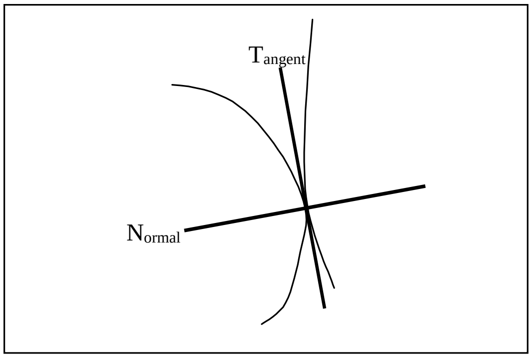

Figure 5.3
Common Normal & Common Tangent Define Surface Contact

2) Assuming no friction, forces are transmitted only along the common normal (See Fig. 5.4).

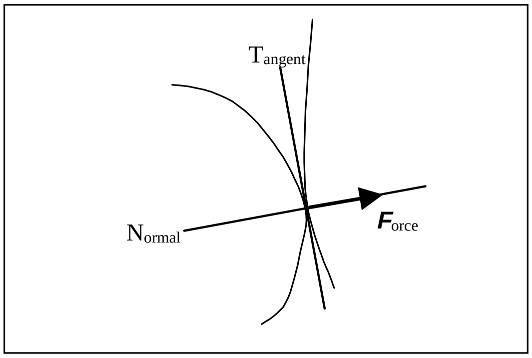

Figure 5.4
Force Transmitted along Common Normal

3) Any frictional forces that do occur will be along the common tangent (See Fig. 5.5).

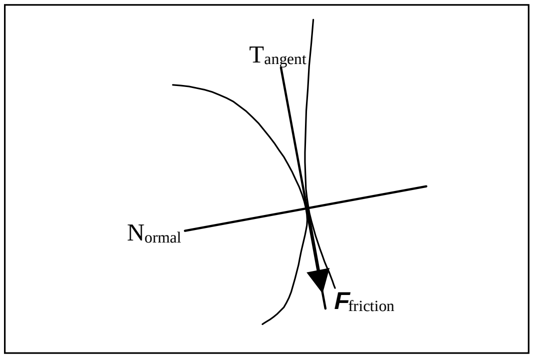

Figure 5.5
Friction Force Occurs along Common Tangent

The design and analysis of almost all surface contact situations can be based on the conditions stated above. One implication of these conditions, known as the law of conjugate geometry states that relative motion can only occur along the common tangent. No relative motion between the bodies can be in the direction of the common normal [Shooter, West & Reinholtz].

Understanding these rules will allow the bit/screw system to be modeled in the next section. In this initial study, friction will be neglected and only the forces transmitted along the common normal will be considered.

5.3 Definition of Surfaces

Before the surface contact laws are applied to the mating of the bit and screw, it should be clarified which bit surface is important, namely the surface at which contact occurs. The surface that will be referred to in this chapter and the next are the surfaces labeled A and B in Fig. 5.6. The surface marked A is a frontal view and the surface B is a side view. These surfaces contact the screw when the bit is used to drive a screw. Figure 5.7 is a sectional view of the bit. In Fig. 5.7 a section of the driving plane can be seen and is marked C. Throughout this chapter and the next, the surface of the bit at which contact occurs will be modeled as a line as it appears at B.

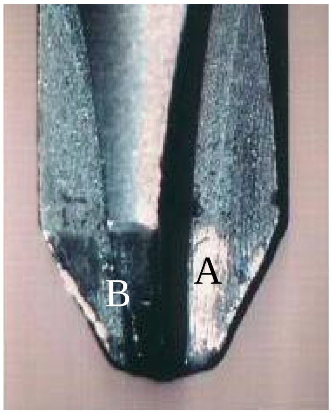

Figure 5.6 Bit Profile

Figure 5.7 Section of Bit

Note the bit model shown in this chapter has a slight taper with respect to the long axis of the bit, as does the surface at B.

5.4 Geometrical Changes and Their Effects on Force Transfer

The wall of the screw that the bit contacts can be modeled as a planar surface terminating at a corner with a small radius. Figure 5.8 displays a sectional view of the bit screw interaction found in Phillip's patent (2,046,837), filed July 3, 1934. In the patent, the planar surface of the screw is labeled as 12 and the corner is labeled as point C.

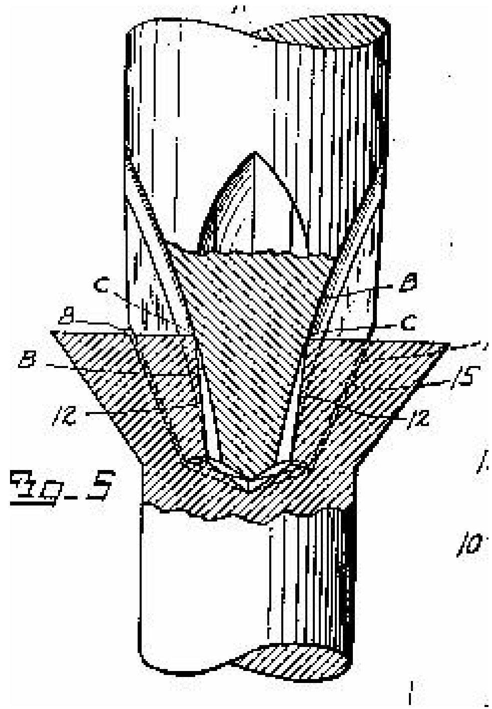

Figure 5.8
Sectional View of Bit/Screw Operating Engagement
(after Phillips Patent # 2,046,837)

The contact occurs at the corner point (point C) of the screw and along the blade of the bit. Since the corner on the screw has a small radius, it is hard to discern a normal and tangent direction. Because the normal and tangent are common to both surfaces, it is easy to show that the model proposed in Fig. 5.9 is accurate. Please note that the model shows only of one of the four wings of the bit/screw interaction, additionally only the surface of the bit that is in contact during the driving of the screw in shown.

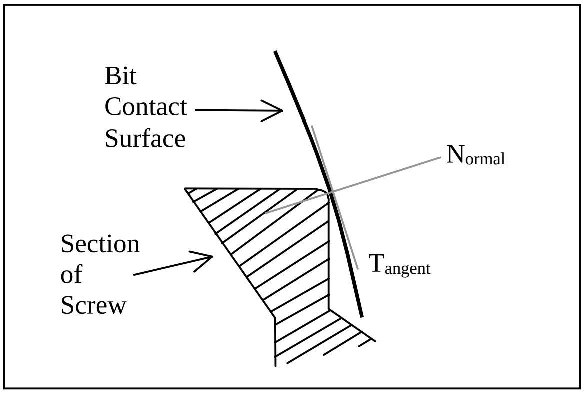

Figure 5.9
Common Normal & Tangent for Bit/Screw Interaction

All non-frictional force transmission will occur along the common normal. Figure 5.10 shows the force of the screw acting on the bit, ***F***.

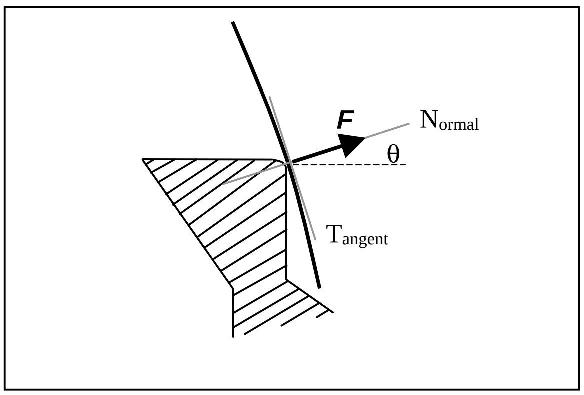

Figure 5.10
Force *F* Acting on the Bit

5.4.1 Geometric Explanation of Cam-Out

The Force ***F***, shown in Fig. 5.10 intersects the horizontal plane, which is perpendicular to the longitudinal axis of the screw, at an angle θ. In the plane shown this force can be separated into two components, namely, $\boldsymbol{F}_{\textbf{horizontal}}$ and $\boldsymbol{F}_{\textbf{cam-out}}$, shown in Fig. 5.11 and defined as follows:

$$\boldsymbol{F}_{\text{horizontal}} = \boldsymbol{F}\cos\theta \qquad (1)$$

$$\boldsymbol{F}_{\text{cam-out}} = \boldsymbol{F}\sin\theta \qquad (2)$$

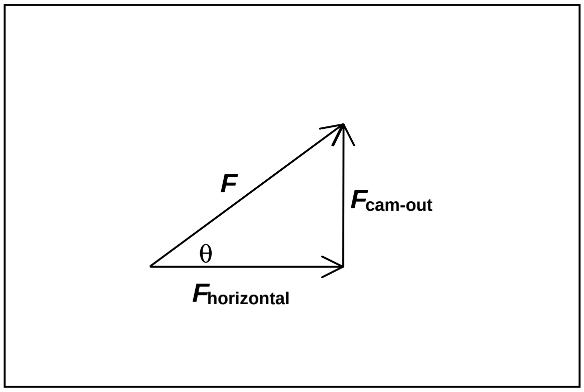

Figure 5.11
Components of Force Vector

As the user applies a torque on the driver, the torque is transmitted to the screw; in the same manner, the screw pushes back on the bit. The force pushing on the bit creates the axial force ($\boldsymbol{F}_{\text{cam-out}}$). Without forces to oppose $\boldsymbol{F}_{\text{cam-out}}$ the bit will separate from the screw.

In addition to the forces $\boldsymbol{F}$, $\boldsymbol{F}_{\text{horizontal}}$ and $\boldsymbol{F}_{\text{cam-out}}$, frictional force and force applied by a user should be included in a model. Figure 5.12 shows all of the forces acting in the case of incipient cam-out. Please note that only a small section of the bit and screw surfaces at the point of contact is shown.

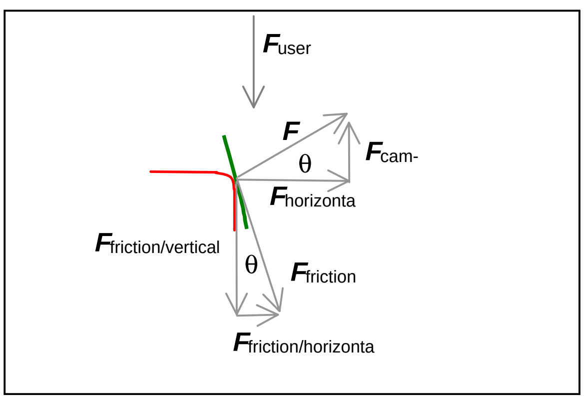

Figure 5.12 Complete Force Balance

Forces of interest are $\boldsymbol{F}_{cam\text{-}out}$, $\boldsymbol{F}_{user}$ and $\boldsymbol{F}_{friction/vertical}$. Equation 3 defines the incipient case.

$$\boldsymbol{F}_{user} = \boldsymbol{F}_{cam\text{-}out} - \boldsymbol{F}_{friction/Vertical} \qquad (3)$$

The expression can be simplified since:

$$\boldsymbol{F}_{cam\text{-}out} = \boldsymbol{F}\sin\theta \qquad (4)$$

$$\boldsymbol{F}_{friction} = \mu\boldsymbol{F} \qquad (5)$$

$$\boldsymbol{F}_{friction/vertical} = \mu\boldsymbol{F}\cos\theta \qquad (6)$$

Resulting in the expression:

$$\boldsymbol{F}_{user} = \boldsymbol{F}(\sin\theta - \mu\cos\theta) \qquad (7)$$

To prevent cam-out, $\boldsymbol{F}_{user}$ must be greater than $\boldsymbol{F}(\sin\theta - \mu\cos\theta)$. Increasing the coefficient of friction (μ) of the bit screw contact, and decreasing the angle of the normal (θ) with horizontal will decrease the cam-out effect.

If the counter force the user applies is not great enough to overcome the cam-out force minus the frictional component, the bit will be forced from the recess resulting in relative motion between the bit and screw. This relative motion will result in the bit scoring against the screw. The end result is altered bit geometry.

5.4.2 The Connection between Wear and Cam-Out

As the bit wears and its geometry is altered, the surface contact relationship is redefined. Figure 5.13 shows the initial contact geometry between the bit and screw in the plane of a screw slot face. The force vector $\boldsymbol{F}_1$**,** having components $\boldsymbol{F}_{horizontal1}$, and $\boldsymbol{F}_{Cam\text{-}out1}$, acts in the direction of the common normal and is at an angle of θ_1 with horizontal. Figure 5.14 shows the contact of bit and screw after the bit is worn. As before $\boldsymbol{F}_2$, $\boldsymbol{F}_{horizontal2}$,and $\boldsymbol{F}_{Cam\text{-}out2}$ represent the force vectors acting of the bit; with $\boldsymbol{F}_2$ acting in the direction of the new common normal which makes an angle of θ_2 with the horizontal.

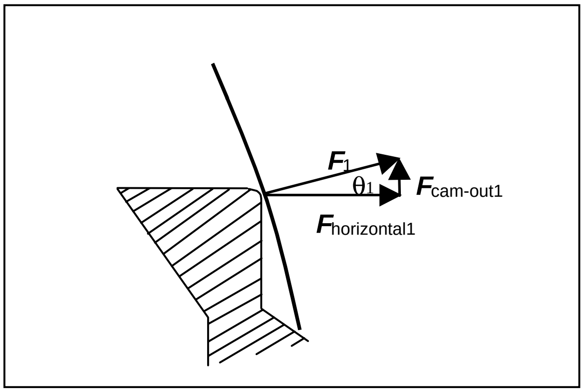

Figure 5.13

Initial Bit/Screw Engagement

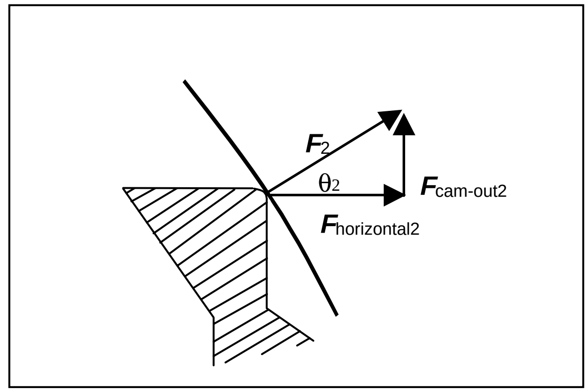

Figure 5.14

Worn-Profile Bit/Screw Engagement

In section 4.5 the wear patterns of the bit was discussed. In that section it was concluded that the largest concentration of wear was at the tip of the bit. It was additionally concluded that the wear pattern also distinctly decreased with distance from the bit. If the bit has greater wear near the tip of the bit than away from the tip, a change in the surface orientation is expected. This change is illustrated in Fig. 5.15.

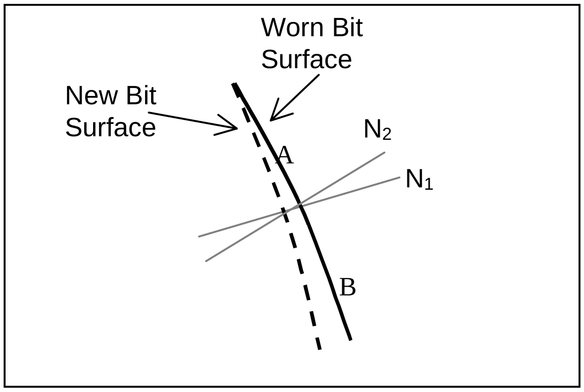

Figure 5.15 Geometric Change of Bit Surface

Figure 5.15 shows the contact surface of the new bit in dashed lines and the worn bit in a solid line. As concluded, at the lower section of the bit marked B more wear occurs that in the upper section marked A. This uneven wear results in a change in the surface's orientation near the contact point. It is additionally seen that the new common normal, $N_{2,}$ will increase its intersection angle, $\theta_{2,}$ with the horizontal over the original common normal N_1. It is therefore concluded that for a given torque, due to the geometric changes associated with wear, the cam-out force will increase with the life of the bit.