THE CONSTRUCTOR.

From example No. 12 we obtain in formula (6a) the value

\[ S_1 = 5 \times 175,000 \times 7.5 \times 2 = 5,350 \text{ lbs.} \]

According to (6a), \( \rho = 0.53 \), and substituting these values in (6a) gives \( S_1 = 10,679 \text{ lbs.} \)

From example No. 10 we have:

\[ S_1 = 5 \times 139,000 \times 7.525 \times 7.525 = 5,602 \text{ lbs.} \]

also \( \rho = 0.44 \), and hence \( S_1 = 12,713 \text{ lbs.} \)

From example No. 37 we have:

\[ S_1 = 5 \times 220,000 \times 7.5 \times 7.5 = 6,570 \text{ lbs.} \]

also \( \rho = 0.526 \), giving \( S_1 = 13,202 \text{ lbs.} \)

From example No. 16, taking \( Q = 125,000 \text{ lbs.} \), we get \( S_1 = 4,867 \text{ lbs.} \); \( \rho = 0.77 \); \( S_1 = 62,800 \text{ lbs.} \); and in No. 17, we have \( S_1 = 651 \text{ lbs.} \); \( \rho = 0.219 \), and \( S_1 = 11,032 \text{ lbs.} \), neither of which are excessive.

The force required to force a hub on an axle upon which it has been pressed, is not materially different from the force with which it was pushed on. The bore of such a hub may also be reduced when necessary by forcing rings upon it. Such rings, when used for car wheel hubs, are usually made of rectangular cross sections, the diameter ranging from 2.5 to 3 in., to 1.5 to 2 in., etc.

An inspection of the table will show that there is a tendency towards increasing pressures. For car wheels, where until quite recently, pressures of 60,000 to 90,000 pounds were used, we now find 60,000 to 80,000 pounds are most frequent, while for locomotive wheels, over 200,000 pounds is the rule.

Midway between the methods of shrinkage, and of cold forcing comes the lesser used method of expansion by use of boiling water. This system secures a much more uniform action of the temperature than is practicable with a red heat, and has been used with excellent results upon the Russian railways for fitting tires to plate wheels. The tires are suspended by a crane, in a tank of water which is kept at the boiling temperature by a jet of steam. The allowance for expansion being a little less than \( \frac{1}{12} \) of an inch to the foot of diameter. An immersion of 10 to 15 minutes is required to obtain the desired expansion. Three workmen can in this manner fit 12 to 14 tires per day of eleven hours. This method also may be found applicable to the fitting of hubs.

65.

DIMENSIONS OF RINGS FOR COLD FORCING.

Since the forms of the various hubs may be taken as cylindrical in nearly every case, the stress may be calculated by the formula already given. It is, however, desirable to present these in such form that they may be used to determine the thickness of the hub which, for increased cold force, may be used to determine the thickness of the hub which, if forced on cold, shall resist a determined force. In (62) instead of the radial stress \( S_r \) substitute the tangential stress \( S_\theta \), giving \( \theta = \frac{2}{1} \frac{S_r}{S_\theta} \), which combined with (62) gives:

\[ \frac{r}{S_\theta} = \sqrt{\frac{S_r r f + S_\theta f - O}{2 \pi r f S_r f}} \] .......................... (65)

In this, \( Q_r \) is the maximum force which the hub can oppose to turning, at the diameter of the fit. If we take the moment of the force tending to rotate the wheel as \( PR \), we must have \( Q_r \geq PR \). \( Q_r \) will then be the force of resistance against slipping in any case. This mode of attachment is then only practicable when \( \frac{r}{S_\theta} \geq S_r f \). By choosing different values for \( S_r \) and \( S_\theta \) various thicknesses for the metal of the hub may be obtained.

Example. The following data are taken from Boring's Express Locomotive at the Vienna Exhibition: Two pairs of coupling wheel of \( 8 \frac{3}{8} \) in. radius, without keys; bore of cylinders \( 27 \) in.; steam pressure \( 170 \) pounds; crank radius \( 5 \) in. If we suppose the entire force upon the piston to act upon a single wheel, we have:

\[ P R = (8 \frac{3}{8} \times 8 \times 1 \times 1) = 33,328 \text{ lbs.} \]

The bore of the wheel is \( 2 \pi r \), hence \( r = 3.56 \) in., then \( f = 7.48 \). This gives:

\[ S_\theta = \frac{356}{7.48} = 47.95 \text{ lbs.} \]

The moment \( 356 \times 2 \) is that which the friction of the wheel upon the axle should be able to resist without slipping. Hence it follows that \( \theta \) must necessarily be greater than 6000. If we take a value of \( \theta = 9000 \text{ lbs.} \), thus giving ample margin against slipping, and also use a wrought iron hub, making \( S_r = 175,000 \text{ lbs.} \), the friction \( f = 62.8 \) lbs., before:

\[ \delta = \frac{3.56 \times 5.28 \times 175,000 \times 7.5 \times 7.5}{175,000 + 175,000} = 1 \]

\[ \sqrt{47.95} = 6.92 \text{ in.} \]

The actual thickness of the hub was 3.56 in.

The ring form is not the only form of construction which may be used for joining members by forcing, since other forms may also be used. An example may be found in Ehrhardt's hanger joint, Fig. 179. In this case clamps of hardened steel

![FIG. 179.](image)

are used to create the pressure. These clamps serve to press the light flanges together, and they may be forced on by use of a screw clamp or other suitable press. Tests of such clamps under steam, pneumatic and hydraulic pressure have shown the joint to be tight and serviceable.

The system of forced connections has grown into extensive use, and appears to be applicable to many forms of construction, and it is to be hoped that the forcing press, for which the firm of Schaeffer & Eudenberg have made suitable pressure gauges, may be found an indispensable tool in all large workshops.

CHAPTER III.

KEYING.

66.

KEYED CONNECTIONS.

The simplest form of keyed connection consists of three parts, viz. the two parts to be connected, and the key itself. The key is made with a slight amount of bevel on both sides, or a greater angle on one side, according to the manner in which the connection is made. The trigonometrical tangent of this angle is called the draft of the key. In Figs. 179 and 200 are shown both forms of keys. For the latter form we will assume that both sides have the same angle.

Let:

- \( \theta \) as the angle of draft,
- \( P \) as the force to be transmitted,
- \( Q \) as the driving force upon the key, normal to \( P \),
- \( Q' \) as the opposing force, tending to drive out the key,
- \( f = \frac{Q}{g} \), the co-efficient of friction between the surfaces of the three parts.

For keys with draft upon one side, we have:

\[ Q = P f g (a + 2 \theta) \]

\[ Q' = P f g (b - 2 \theta - c) \]

In order that \( Q' \) should not be negative and the key come out of itself, we must have \( a + 2 \theta \leq b - 2 \theta - c \).

For \( P = Q, 1 \) this gives \( 2 \theta < \pi \).

For keys with draft on both sides we have approximately:

$$Q = \frac{P}{g} \left( a + b \right)$$

(66)

$$Q' = \frac{P}{g} \left( a - b \right)$$

In this case it is necessary to keep below the full value of \( \frac{g}{a} \) for each edge of the key in order that the connection may not be pinched itself apart. The total draft will be found to have approximately the same minimum value as in the previous case.

In practice it has been found that keys which have shown endurance and resistance under load, have been made with a total draft of \( \frac{g}{a} \), and even \( \frac{g}{a} \) or less, while others made with \( \frac{g}{a} \), \( \frac{g}{a} \), or sometimes \( \frac{g}{a} \) are less secure.

The load upon a key may act in three different manners each of which may again be positive or negative. In the first, the load acts normal to the base of the wedge, as at \( Q, K \), Fig. 181, or as \( P \), in Fig. 179 and 180; and for this form, the term Cross Key may be used. The second case occurs when the load acts normal to the plane \( K J \), as \( K L \), in Fig. 181, which may be called a Longitudinal Key. The third case is that in which the force acts normal to the plane \( Q K \), as \( K H \), Fig. 181, which may be called a wedge key.

\[ \frac{67}{68} \]

**CROSS KEVLED CONNECTIONS.**

In Fig. 182 we have an example of a cross keyed connection. The rod and the key are both of wrought iron, the boss is cast iron. The stresses for a given force \( P \) upon the rod are: the bending stress upon the key, as in Case VII. \( \frac{5}{8} \) [Stress \( S_1 \)]; the shearing stress between the key and the inner edge of the boss (Stress \( S_2 \)), and the tension upon the segment shaped sections of the rod on both sides of the mortise for the key (Stress \( S_3 \)). If, according to \( \frac{62}{68} \), we make \( S_2 = 0.8 S_1 \), and \( S_3 = S_1 \), we have:

$$\frac{b}{d} = \frac{5}{8} \frac{f}{s}$$

(68)

(69)

If we make \( h = 0.5 d \), \( b = d \), \( h = 0.25 d \), or say \( d \), we shall have good practical proportions. In Fig. 183 we have two wrought iron rods coupled by wrought iron keys. In this case a wrought iron above is used, whose thickness \( d = 0.25 d \). Fig. 181 shows a form similar to Fig. 182, except that the key passes below the boss, instead of going through it, while in Fig. 183 the key is let into the side of the rod.

The pressure upon the base surface of the key in the case of Fig. 182 may be taken as:

$$n = \frac{P}{b} \left( \frac{0.754}{a} - \frac{1}{2} \right) S_3$$

(70)

which gives \( p = 2 \). [Stress \( S_4 \)].

If the pressure becomes yet higher for the method shown in Fig. 184, for which case the value of \( S_4 \) should not be taken too great. If the connection is intended to be taken apart frequently, the value of \( p \) should not be allowed to be too great. This may be accomplished either by reducing the value of \( S_4 \) or by providing an increased cross section of metal about the mortise of the key, or by extending the surface by means of cutters or gibs, as shown in Fig. 185. The key may then be made smaller than already given above. The forms of keyed connection shown are used for example in the rod connections of water wheels, and in similar cases.

In Fig. 187 is shown a method of keying a foundation bolt. The gib or cutters are used to increase the strength. Following the calculations of \( \frac{12}{68} \), the depth of the three pieces may be made alike in the middle. The washer plate in the foundation masonry should be arranged so as to give access to a nut on the lower end of the bolt, and this can be tightened by hand until the bearing is thrown upon the key, and the driving in of the latter brings all the parts firmly together.

**LONGITUDINAL KEYS.**

Keys of this class are principally used to secure the hubs of wheels to their shafts or axles. For this purpose they may be considered as divided into three classes, as follows:

- Concave, or hollowed keys. Fig. 188. 1.
- Flat surface keys. Fig. 188. 2, 4, 5.
- Recessed keys. Fig. 188. 6, 7, 8.

The Concave key is only suitable for constructions involving small resistance, and acts merely by the friction due to the pressure which it causes. The flat surface key is capable of resisting much greater force and vibration, and when used in the multiple manner shown in 4 and 5, it makes a secure and efficient fastening. The recessed key, shown in 6, affords a very secure method of fastening hubs to shafts to which they have been closely fitted, and is simply and readily made. Keys of this kind are also used as an additional precautionary fastening for hubs which have been forced on.

In determining the dimensions of keys it will be found most convenient to use empirical methods, except in cases of great vibration; the following formula will be found to cover the usual range of work. The material for the key is taken as steel, and distinction is made between cases in which the hub is subjected merely to endlong pressure, and those where torsional stresses exist. The former may be called draft keys, the latter torsion keys.

If we call the diameter of the shaft \( D \), the breadth of the key \( S \), and the middle depth of the key \( S_1 \) we have:

$$S = 0.24'' - \frac{D}{3}; S_1 = 0.16'' + \frac{D}{3}$$

for Draft keys.

$$S = 0.16'' + \frac{D}{5}; S_1 = 0.16'' + \frac{D}{10}$$

for Torsion keys.

The taper of such keys is made about \( \frac{1}{10} \).
For the more commonly occurring diameters we have the following proportions:

\[ D = 1'' \quad 2'' \quad 3'' \quad 4'' \quad 5'' \quad 6'' \quad 7'' \quad 8'' \quad 9'' \quad 10'' \]

For Draft Keys:

\[ S = \frac{1}{16}'' \quad \frac{1}{8}'' \quad \frac{1}{4}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \quad \frac{1}{2}'' \]

For Tapered Keys:

\[ S = \frac{1}{16}'' \quad \frac{1}{8}'' \quad \frac{1}{8}'' \quad \frac{1}{4}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \quad \frac{1}{2}'' \quad \frac{3}{8}'' \]

For shafts of less diameter than 1'', we may make \[ S = \frac{1}{16}'' \], \[ S = \frac{1}{32}'' \]. If several keys are to be used, they may be made the same dimensions as single keys. For hubs which have been forced on, and hence would be secure without any key, the dimensions for draft keys may be used.

**§ 70.**

**Edge Keys.**

When the pressure upon a key acts at right angles to the plane of its length, the difference between the positive and negative direction of the forces is readily distinguishable.

![Diagram of Edge Keys](image)

When the pressure acts as in Fig. 189, the combination is insecure, since the only binding action of the key is that due to the pressure, and consequent friction between the parts. If the base of the key is rough, and the inclined face smooth, the action of a force in the direction \( H' \), tends to tighten the parts together. An application of this action is shown in the curved key of Kemaal, shown in Fig. 190. When the hub is rotated in the direction of the arrow, the action is the same as that of the force \( H' \) in the preceding case, and the shaft is firmly grasped. A countersunk screw at \( s \), is used to tighten the key, and a similar one at \( h \), to loosen it. This principle will be discussed later, under the subject of couplings.

**Fig. 189.**

**Fig. 190.**

**Fig. 191.**

**Unloaded Keys.**

The force \( P \), which under ordinary conditions bears upon a key, may be various methods be supported by other means; the key in such a case may be said to be unloaded. Such constructions offer a much greater security, and permit much lighter keys, than the methods previously described. A few examples will serve to illustrate.

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*See S. F. Burgh, Modern Screw Propeller, London, 1889.*