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*Review Article*

# DESIGN AND ANALYSIS OF ROLLING KEY—A REVIEW

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Mechanical power presses are dangerous machines and have caused many accidents over the years, these accidents are mostly occuring due to the failure of key. The biggest hazard when working with either full or part revolution mechanical power presses is the point of operation. A hand or any body part in this area can result in crushed. The failure of key leads to failure of Power press system which is a major concern. The objective of the present work is to study the causes of failure of key. It is find out that key is fails due to the shearing and crushing of key. Modeling of the key and analysis using finite element analysis help in understanding causes of failure of key.

Keywords: Key failure, Mechanical power press, Material, Shear failure, Bearing failure

## INTRODUCTION

A mechanical power press performs various operations such as shearing, punching, forming, bending. The power press activated through a foot paddle, once the paddle stroke, press performs a full stroke, barring any mechanical failures, before stopping at top dead center. When key is fails machine remains in continuous running position. This inability to stop the machine stroke posses a hazard to the operator and other workers. The biggest hazard when working with either full or part revolution mechanical power presses is the point of operation. Mechanical presses are used several types of drive mechanisms. These drives include eccentric crankshaft, knuckle joint, etc. These drives are used to convert rotational motion given by a motor into linear motion of the ram. These presses are recommended for blanking and punching operations as the involved drives are capable to achieve very high forces at the end of their strokes.

### Functions of Key

- The primary function of key is to transfer torque from the rotating shaft to the rotary element of the machine. The same key works to transmit torque in both directions,

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from shaft to the machine element or from machine element to the shaft.

- The second function of the key is to restrict relative rotational motion and axial movement between the shaft and the machine element.

## Main Parts of Power Press

### Base

Base is the one of the parts of a press. It is main supporting member for workpiece holding dies and different controlling mechanisms of press. Size of the table limits the size of workpiece that can be processed on a press.

### Frame

Frame constitutes main body of the press located at one edge of its base. It houses support for ram, driving mechanism and control mechanisms. Some of the press have column shaped frame.

### Ram

This is main operating part of the press which works directly during processing of a workpiece. Ram reciprocates to and fro within its guideways with prescribed stroke length and power. The stroke length and power transferred can be adjusted as per the requirements. Ram at its bottom end carries punch to process the workpiece.

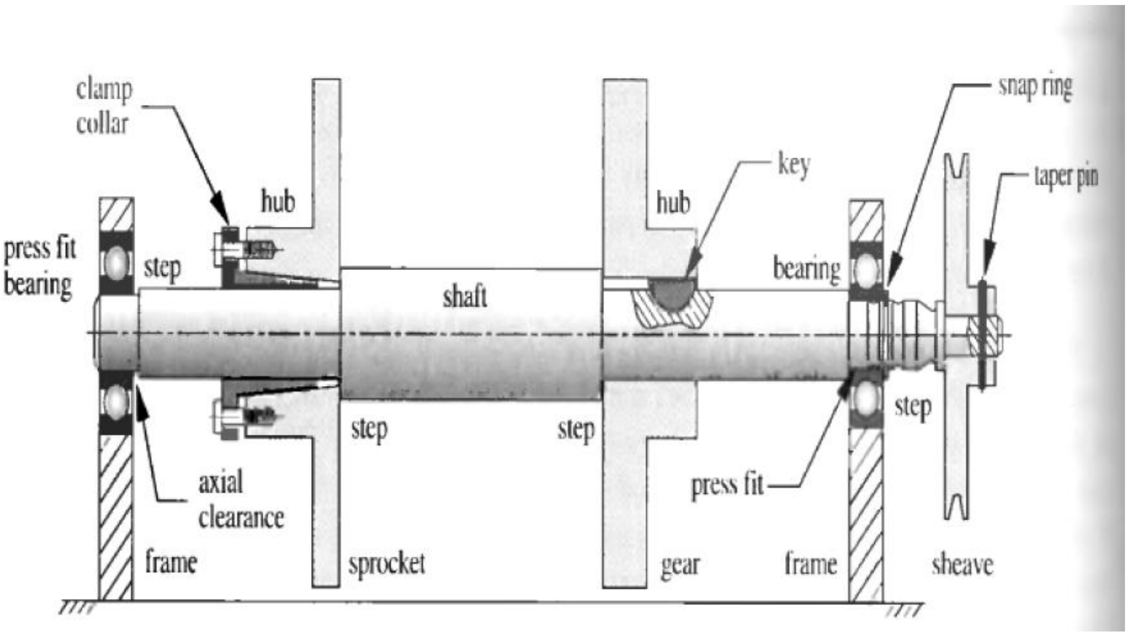
### Pitman

It is the part which connects the ram and crankshaft or ram eccentric.

### Driving Mechanism

Different types of driving mechanisms are used in different types of presses like cylinder and piston arrangement in hydraulic press, crankshaft and eccentric mechanisms in mechanical press, etc., these mechanisms are used to drive ram by transferring power from motor to ram.

Figure 1: Position of Key on Shaft



## Controlling Mechanisms

Controlling mechanisms are used to operate a press under predetermined controlled conditions. Normally two parameters are adjusted by controlling mechanisms length of stroke of ram and power of stroke. Transfer of power can be disengaged with the help of clutch provided with driving mechanisms as per need (Raghuwanshi, 1998).

## Key Details

A key is a piece of steel inserted between the shaft and hub or boss of the pulley to connect these together in order to prevent relative motion between them.

## Key Material

Because key are loaded in shear, ductile material are used soft low carbon steel is the most common choice unless a corrosive environment is required brass or stainless steel key. Square and rectangular keys are often made from cold rolled bar stock and merely cut to length tapered and woodruff key are made from soft cold rolled steel (Robert Norton, 2006).

## Stresses in Key

There are two modes of failure in key: shear failure occurs when key is sheared across its width at the interface between shaft and hub bearing failure bearing failure occurs by crushing either side in compression.

**Shear Failure:** Average shear stress due to direct shear is defined in equation

$$^{2}{}_{xy} = F/A_{shear}$$

where $F$ is applied force $A_{shear}$ is the shear area being cut. In this case $A_{shear}$ is the product of the keys width and length. The force on key can be found from the quotient of the shaft torque and the shaft radius. If the shaft torque is constant with time, force will be also safety factor can be found by comparing the shear stress to the shear yield strength of the material. If the shaft torque is time varying then fatigue failure of the key in shear is possible. The approach is to compute mean and alternative shear-stress component and use them to compute mean and alternative von mean stresses (Robert Norton, 2006).

**Bearing Failure:** The average bearing stress is defined by equation

$$\pm_{xy} = F/A_{bearing}$$

where $F$ is the applied force and the bearing area is the area of contact between the key side and the shaft or the hub. For square key this will be its half height times its length. A woodruff key has a different bearing area in the hub than in the shaft. The hub's woodruff bearing area is much smaller and will fail first. The bearing stress should be calculated using maximum applied force, whether constant or time varying. Since compressive stress do not cause fatigue failures, bearing stress can be considered static. The safety factor is found by comparing maximum bearing stress to the material yield strength in compression (Robert Norton, 2006).

## Basic Design of Key

Let

$T$ = Torque transmitted by the shaft,

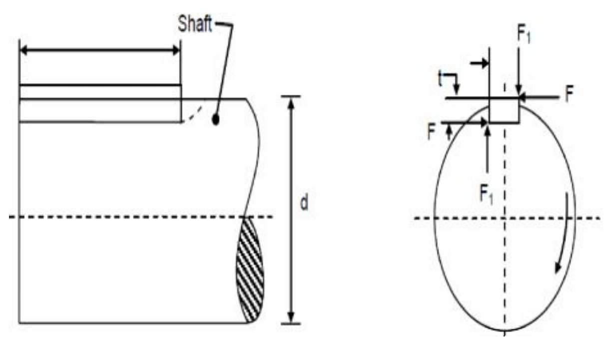
$F$ = Tangential force acting at the circumference of the shaft,

$d$ = Diameter of shaft,

$l$ = Length of key,

$w$ = Width of key,

Figure 2: Forces Acting on a Sunk Key




*t* = Thickness of key, and

² and ±$_c$ = Shear and crushing stresses for the material of key.

Considering shearing of the key, the tangential shearing force acting at the circumference of the shaft,

*F* = Area resisting shearing x Shearing stress

= *l* × *w* × ²

∴ Torque transmitted by the shaft,

*T* = *F* × *d*/2 = *l* × *w* ×²

Considering crushing of the key, the tangential crushing force acting at the circumference of the shaft,

F = Area resisting crushing x Crushing stress

= l × *t*/2 × ±$_c$

∴ Torque transmitted by the shaft,

*T* = *F* × *d*/2 = *l* × *t*/2 × ±$_c$ × *d*/2

∴ Length of key is calculated

*l* = 1.571 *d*

## MATERIAL SELECTION

The selection of materials and the processes used in fabrication are integral parts of the design of any machine component. Material selection for machine component is as follow,

- Identify characteristics of the application
- Identify component specifications
- Identify required material properties
- Select potential material candidate considering cost, availability, etc.
- Fabrication of component
- Verification testing/evaluation and failure analysis of component
- Specify best material

A rational method of selecting materials is to utilize failure analysis of similar parts (to a new design) that have failed in service. Materials are selected that are unlikely to fail based on the knowledge gained from a failure analysis for the component. Table 1 identifies material properties that are related to common failure modes.

Shaded block at intersection of material property and failure mode indicates that a particular material property is influential in

Table 1: Relations Between Failure Modes and Material Properties

| | Material property | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Failure mode | Ultimate tensile strength | Yield strength | Compressive yield strength | Shear yield strength | Fatigue properties | Ductility | Impact energy | Transition temperature | Modulus of elasticity | Creep rate | $K_{Ic}$ | Electrochemical potential | Hardness | Coefficient of expansion |
| Gross yielding | | ■ | | ■ | | | | | | | | | | |
| Buckling | | | ■ | | | | | | ■ | | | | | |
| Creep | | | | | | | | | | ■ | | | | |
| Brittle fracture | | | | | | | ■ | ■ | | | ■ | | | |
| Fatigue, low cycle | | | | | ■ | ■ | | | | | | | | |
| Fatigue, high cycle | ■ | | | | ■ | | | | | | | | | |
| Contact fatigue | | | ■ | | | | | | | | | | | |
| Fretting | | | ■ | | | | | | | | | ■ | | |
| Corrosion | | | | | | | | | | | | ■ | | |
| Stress-corrosion cracking | ■ | | | | | | | | | | | ■ | | |
| Galvanic corrosion | | | | | | | | | | | | ■ | | |
| Hydrogen embrittlement | ■ | | | | | | | | | | | | | |
| Wear | | | | | | | | | | | | | ■ | |
| Thermal fatigue | | | | | | | | | | ■ | | | | ■ |
| Corrosion fatigue | | | | | ■ | | | | | | | ■ | | |

controlling a particular failure mode (Frank Kreith, 1999).

## PARAMETERS AFFECTING THE FAILURE

- Failure by fracture due to static overload, the fracture being either brittle or ductile.
- Buckling in columns due to compressive overloading.
- Yield under static loading which then leads to misalignment or overloading on other components.
- Failure due to impact loading or thermal shock.
- Failure by fatigue fracture.
- Creep failure due to low strain rate at high temperature.
- Failure due to the combined effects of stress and corrosion.
- Failure due to excessive wear.

### Failure Due to Fracture

The fracture can be classified either as ductile or brittle depending upon whether or not plastic deformation of the material before any catastrophic failure.

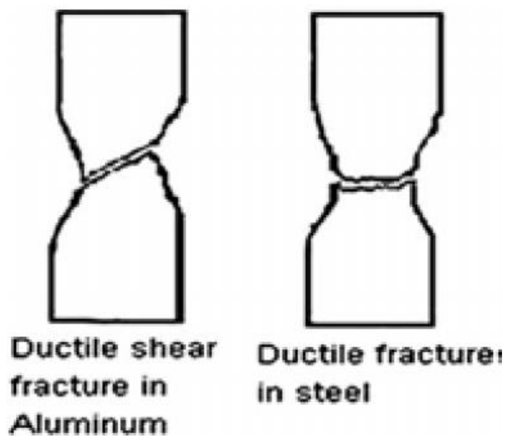
### Ductile Fracture

Ductile fractures are associated with overload of the structure or large discontinuities. This type of fracture occurs due to error in design, incorrect selection of materials, improper manufacturing technique and handling. Figure 2 shows the features of ductile fracture.

### Brittle Fracture

Brittle fracture is characterized by rapid crack propagation with low energy release. The brittle fracture occurs due to material imperfection, sharp corners and notches in the component (Maleque and Salit, 2013).

Figure 3: Ductile Fracture in Aluminum and Steel After Tensile Testing




In Failure Analysis of Electric Disconnector it is observed that, the disconnector fails due to brittle fracture. At investigation it was found that the fractured disconnector for a 500 kV substation was failed during installation that cause of failure is unknown. Therefore, thorough destructive examinations it was found out that Si percentage is quite high and contributes significantly to the brittle nature of the disconnector material. It is recommended that the percentage of Si of the alloy be reduced as it promotes brittleness of the material (Maleque and Masjuki, 1997).

## FAILURE DUE TO FATIGUE

Metal fatigue is caused by repeated cycling of the load. It is a progressive localized damage due to fluctuating stresses and strains on the material and fatigue cracks initiate and propagate in regions where the strain is most severe (Maleque and Salit, 2013). From informal studies observed that fatigue- caused failures are much higher. For motor applications, it climbs into the 90% range when the effects of corrosion and new stress raisers are considered. In shaft failure it is observed that the cracks are start in the key way. The keyway on the take-off end or driven end of the shaft is the one of most concern because it is located in the area where the highest shaft loading occurs. When this loading has a high torsional component, fatigue cracks usually start in the fillets or roots of the keyway (Austin Bonnett, 2000). Fatigue performance improves by improvements in design. Following are the design guideline which is effective in controlling or preventing fatigue failure:

- Eliminate or reduce stress raisers by streamlining the part or component.
- Avoid sharp surface tears resulting from punching, stamping, shearing, or other processes.
- Prevent the development of surface discontinuities during processing.
- Reduce or eliminate tensile residual stresses caused by manufacturing.
- Improve the details of fabrication and fastening procedures.

## FAILURE DUE TO CORROSION

Corrosion is the gradual destruction of materials by chemical reaction with their environment. Corrosion is chemically induced damage to a material that results in deterioration of the material and its properties. This may result in failure of the component.

Corrosion can be minimized or controlled by proper selection of material, design, coatings, and occasionally by changing the environment.

## STRESS CONCENTRATION

The presence of a notch, or any sudden change in section of a piece of material, can vary significantly change the stress at which fracture occurs. The notch or sudden change in section produces what are called stress concentrations. They disturb the normal stress distribution and produce local co-generations of stress. The amount by which the stress is raised depends on the depth of the notch, or change in section, and the radius of the tip of the notch. The greater the depth of the notch the greater the amount by which the stress is increased. The smaller the radius of the tip of the notch the greater the amount by which the stress is increased. This increase in stress is termed the stress concentration factor.

One way of arresting the progress of such a crack is to drill a hole at the end of the crack to increase its radius and so reduce the stress concentration. So by increasing the radius of the notch stress concentration can be reduced. (Maleque and Salit, 2013).

## WEAR

Wear is the erosion of material whenever two surfaces in contact experience relative sliding motion under the action of a contact force. Wear can be adhesive, abrasive. Wear rate is usually a material property and directly related to the hardness of the material (Abhijit Dasgupta and Michael Pecht, 1991). Following are the ways and means to prevent or reduce the wear.

- The choice of a suitable lubricant and lubrication method
- Improve working conditions

- The correct choice of material, in accordance with the basic form of wear
- Improve the quality of repair
- A surface treatment (Maleque and Salit, 2013).

### Failure Can be Reduced by Following Ways

- Changing the material having desired property fatigue failure and brittle fracture and ductile fracture can be reduced.
- Changing the geometry of the component, we can reduced ductile fracture, fatigue failure and stress concentration decreases.
- Improving the working conditions, wear can be reduced.
- By surface treatment can reduce wear.
- Proper manufacturing techniques, ductile fracture can be reduced.
- By proper lubrication of component wear can be reduced.

### Fuzzy Identification

Failure is identified with the help of failure cases. Failure cases are very important for failure analysis. Firstly, according to the collection of large accident case, summarized how to deduce the failure features and failure information of each failure modes may have. Then identify the possibilities of the new failure case belong to each kind of existing failure mode, using the fuzzy identification and then judge which failure mode the failure case is most likely belongs to (Qingmei Wang and Peng Shi, 2009).

### Finite Element Analysis

The most common problem in creating a machine or structure with good strength-to-weight ratio is to identify its critical locations and the corresponding maximum stresses or strains and to adjust the design optimally. This is difficult if a member's geometry, including the geometry and time-dependence of the loading, is complex. The modern analytical tool for addressing such problems is Finite Element Analysis (FEA) or Finite Element Modeling (FEM). The FE method is a way of getting a numerical solution to a specific problem. An FEA does not produce a formula as a solution, nor does it solve a class of problems. Also, the solution is approximate unless the problem is so simple that a convenient exact formula is already available (Frank Kreith, 1999).

For the analysis of power press FEM is used. The first stage involves the modelling of the C-frame power press in Pro/E software. The 3D model of the power press is analyzed in static condition to find the stresses and deflections in the structure. The second stage involves the reduction in weight of the power press by varying or reducing the thickness of frame and bed and the press is analysed in static condition to find the result (Ravi, 2014). Optimization of Keyway Design shows, how numerical Fnite Element (FE) analysis can improve the prediction of stress concentration in the keyway (Niels Pedersen, 2010).

## CONCLUSION

From the above Study it can be conclude that, the failure occurs due to shearing, crushing, overloading, fatigue, corrosion, wear and increase in stress concentration factor. By changing geometry, changing material, proper lubrication, coating of machine component, failure is reduced. For finding the major causes of key failure, we have to check the material properties of the present key and design, then with the help of the FEA analysis stress analysis is to be carried out. FEA analysis is helpful in finding the main cause of failure of rolling key.

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