Development of a Manually Operated Hydraulic Press and Pull Machine

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Abstract — A hydraulic press and pull machine comprising of a frame, cylinder and piston, two threaded studs, hydraulic pump and hose, pulling clamp and a workpiece support was designed, fabricated and evaluated. The machine is manually operated. The maximum shear force, maximum bending moment and maximum displacement of the machine workpiece support were determined as 74.9491N, 16.635N-m and 4.367e\(^{-7}\)mm for a simulated load of 1000N. Maximum axial, bending and torsional stresses were also determined as 0.00359, 701998 and 0.00655N/m\(^2\) respectively. Performance of the developed machine was determined using seven bearings of bore diameters 24, 30, 40, 50, 65, 80 and 100mm respectively, fitted into seven corresponding shafts with shaft deviation of ±0.001mm and dismantled afterwards using three different methods: traditional hammering, the developed manual hydraulic press and pull machine and already existing electrically powered hydraulic press. The results of the experiments showed that traditional hammering is the most time consuming method of mounting and dismounting force fits, followed by the use of the developed press-pull machine while electrically powered hydraulic presses are the fastest. The machine which was fabricated with local materials will reduce the time and stress associated with installation and removal of bearings, and other forms of force fits in machine assemblies. Hence, leading to an overall improvement in the standard of machines/equipment fabricated in Nigeria.

Keywords — Bearing, fastening, housings, machine, press fitted elements, shafts.

1 INTRODUCTION

Press fit or friction fit, is an interference fit fastening between two parts which is achieved by friction after the parts are pushed together, rather than by any other means of fastening. Typical examples of interference fits are the press fitting of shafts into bearings or bearings into their housings and the attachment of watertight connectors to cables. An interference fit also results when pipe fittings are assembled and tightened.

In many workshops (especially small and medium scaled workshops), repair and replacement of press fitted machine elements are done in a crude manner. This process wastes time and consumes a lot of energy, as well as cause harm to the environment. Also the material to be replaced or the machine/plant on which the repairs is being carried out on may get damaged in the process. The ability of a technician to carry out his job safely, with less time and energy application depends on the availability of the right working tools. To perform jobs such as Pushing, pulling, thrusting and rotation, presses are required.

For instance, the installation of bearings into housings or shafts and the extraction of such from a housing or shaft depend largely on the tools and methods used. If bearings are not properly installed or removed, the effect is felt on the entire assembled machine. Also improper installation of bearing causes vibration in rotating parts and affects the geometric precision and surface integrity of the balls and rollers (Khurmi and Gupta, 2006). Presses can be divided into the following categories: Hydraulic Presses which operate on the principles of hydrostatic pressure, Screw presses which use power screws to transmit power and Mechanical Presses which utilize kinematic linkage of element to transmit power (Niebel et al, 2007; Degarmo et al, 1997; Sharma, 2005).

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The major advantages of hydraulic presses over the other types of presses (power screw and mechanical presses) include: hydraulic press provides a more positive response to changes in input pressure, the force and pressure can accurately be controlled, and the entire magnitude of force is available during the entire working stroke of the ram travel (Butcher, 2004; Sullivan, 2000; Cockbain, 1998; Doring, 1998). Hydraulic presses are preferred when very large a nominal force is required, hence the best option for mounting and dismounting force fits (Lange 1975). The hydraulic press is therefore a valuable equipment in the workshop and laboratory especially for press fitting operations and for the deformation of materials such as in metal forming processes and material testing for strength (Dagwa and Ighadode, 2005; Harding, 1996).

Unfortunately, all such presses are imported into Nigeria and as such, cannot be afforded by small and medium scaled workshops or artisans. Also, existing presses are electrically powered, which may not be readily available in small workshops. It is therefore important to design and manufacture a manually operated low cost hydraulic press, using locally sourced materials like mild steel bars, pipes and rods, rubbers hoses, etc.

The development of the manually operated hydraulic press and pull machine will bring relief to workshops (especially small and medium scaled) by reducing the time and stress associated with installation and removal of bearings, and other forms of force fits in machine assemblies, thereby ensuring easier and cheaper maintenance and repair of machines and plants. Since all parts of the machine were built with locally sourced materials, this project therefore reduces dependence on imported goods and promotes indigenous technology.
2 METHODOLOGY

2.1 DESIGN CONCEPTS AND CONSIDERATIONS

The design, material selection and development of the manually operated hydraulic press and pull machine were based on the following concepts and considerations:

i. The machine was designed with provisions for adjustment, such that bearings of different diameters can be fit into shafts or housings of different diameters and lengths.

ii. The hydraulic fluid is pumped manually, thus ensuring that the machine does not require electrical energy for its operation thereby incurring no operational cost.

iii. The machine was fabricated using locally sourced and available materials for easy operation, maintenance and repair/replacement in case of breakdown. Also, standard components/parts were used where necessary to ensure low cost of production and maintenance of the machine.

2.2 DESIGN ANALYSIS AND MATERIALS SELECTION

Hydraulic cylinders are tubular structures in which a piston slides when hydraulic fluid is admitted into it. The design requires include: the minimum wall thickness of the cylinder, the end cover plate and the flange thickness (Sumaila, 2002). The minimum wall thickness, T of the hydraulic cylinder was computed to be 12mm using equations 1 and 2 below (Khurmi and Gupta, 2006).

\[ T = p \left( \frac{6t}{p - 2t} \right)^{1/2} - 1 \]  

\[ p = \frac{4T\delta t}{d} \]  

Where; \( r_1 \) = Internal radius of cylinder = 50x10^{-3}m

\( p \) = Internal fluid pressure = 3.82 N/m²

\( \delta \) = Tangential stress = 480x10⁶ N/m² (Khurmi and Gupta, 2006).

\( \delta t \) depends on the material from which the cylinder was made.

The cylinder end cover plate thickness \( T_{cP} \) was determined as 9.6mm using equation 3.

\[ T_{cP} = KD \left( \frac{p}{\delta t} \right)^{1/2} \]  

Where; \( D \) = Diameter of end cover plate = 0.1m

\( K \) = coefficient depending upon the material of plate = 0.4 (Khurmi and Gupta 2006)

The flange thickness \( t_f \) may be obtained by considering the bending of the flange about a section where the flange is weakest in bending. Thickness of the flange was therefore determined as 49mm using equation 4.

\[ t_f = \frac{6M}{bb_f} \]  

Where; \( b \) = width of flange at the section under consideration

\( \delta t \) = shear stress of flange material

\( M \) = resultant bending moment

Stress analysis of the workpiece support which is the major load carrying member was done using Solidworks 2015 simulation to determine the maximum shear stress, maximum bending moment and the displacement on the beam when loaded to deformation. This was done by first designing the part using Solidworks design software. After the design, the part was assigned the material mild steel from the Solidworks material database and the ends were restrained. Force (load) was then applied to the part until it deformed. Maximum shear stress, maximum bending moment and the displacement on the beam when loaded to deformation was then displayed by the software. Solidworks uses the maximum von Mises stress criterion to calculate these parameters. This criterion states that a ductile material starts to yield when the equivalent stress (von Mises stress) reaches the yield strength of the material (Khurmi, 2010; Dassault Systemes, 2014). The yield strength (SIGYLD) is a material property which is defined as stress at which a material begins to deform plastically. Table 1 below shows the model with its material properties. When loads are applied to a body, the body tends to absorb its effects by developing internal forces that, in general, vary from one point to another (Khurmi, 2010). The intensity of these internal forces is called stress. The units of stress are force per unit area. For an estimated load of 1000N, determined by adding the weight of the workpiece and the force (press fitting force) produced by the hydraulic pump, the beam forces and resultant stresses are shown in tables 2 and 3 respectively. Also, the nodal stress plot, which shows the stress distribution on the component under load and the static displacement plot showing displacement along the workpiece support length were generated by the analysis. These were displayed in figures 1 and 2 respectively. In figure 1, the regions in red indicate regions that will experience maximum bending stress while the blue regions are the regions where bending stress is minimum. The green region indicates regions with intermediate value. Similarly, red regions in figure 2 indicate regions that will experience maximum deflection if the beam fails whereas the blue region will experience minimum deflection. Hence, bending stress is maximum at the ends of the support beam while deflection is maximum at the centre, where the workpiece rests.

Table 1: Material Properties (Solidworks 2015 simulation)

| Material | Property | Value |
|----------|----------|-------|
| Mild Steel | Yield strength | 745 MPa |
| Mild Steel | Tensile strength | 745 MPa |
| Mild Steel | Shear modulus | 69 GPa |
| Mild Steel | Poisson's ratio | 0.3 |
| Mild Steel | Density | 7850 kg/m³ |
| Mild Steel | Thermal expansion | 12.25 x 10⁻⁶ K⁻¹ |

Table 2: Load and Displacement

| Component | Load | Displacement |
|-----------|------|--------------|
| Beam | 1000N | 0.02 m |
| Support | 500N | 0.01 m |

Table 3: Stress Distribution

| Component | Maximum Shear Stress | Maximum Bending Moment |
|-----------|----------------------|------------------------|
| Beam | 120 MPa | 1000 Nm |
| Support | 60 MPa | 500 Nm |
### Table 2: Beam forces resolution

| Beam Name          | Joints | Axial (N)   | Shear (N)   | Shear2 (N)  | Moment1 (N.m) | Moment2 (N.m) | Torque (N.m) |
|--------------------|--------|-------------|-------------|-------------|---------------|---------------|--------------|
| Workpiece support  | 1      | 4.643       | 3.53        | 74.9        | -             | 1.66          | -            |
|                    |        | 06e-006     | 553e-009    | 491         | 16.7          | 364e-007      | 1.774        |
|                    | 2      | 4.671       | 3.26        | 64.9        | -             | 1.69          | -            |
|                    |        | 08e-006     | 339e-009    | 554         | 16.6          | 229e-007      | 1.788        |

### Table 3: Resultant stresses

| Beam Name          | Joints | Axial (N/m²) | Bending Dir1 (N/m²) | Bending Dir2 (N/m²) | Torional (N/m²) | Worst Case (N/m²) |
|--------------------|--------|--------------|---------------------|---------------------|-----------------|------------------|
| Workpiece support  | 1      | 0.00357      | 70710               | -                   | 0.005884        | 707101           |
|                    |        | 158          | 1                   | 67                  | -               | 0.0065           |
|                    |        |              |                     |                     |                 | 2554             |
|                    | 2      | 0.00359      | 70199               | -                   | 0.005985        | 701998           |
|                    |        | 314          | 8                   | 99                  | -               | 0.0065           |
|                    |        |              |                     |                     |                 | 786              |

### 2.3 Machine Manufacturing Procedure/Description

The developed machine comprises of the following parts: frame, cylinder and piston, two threaded studs, hydraulic pump and hose, pulling clamp and a workpiece support. Figure 3 shows the isometric view of the machine with the main components identified.

The frame (Fig. 4) is the main supporting structure upon which other components of this plant are mounted. The frame is a welded section constructed from 8 mm thick mild steel U-channel bar to withstand direct tension imposed on the pillars. The frame provides mounting points and maintains proper relative positions of the units and parts mounted on it over the period of service under all specified working conditions. It also provides general rigidity of the machine (Acherkan, 1993).

The cylinder is a 50 mm diameter hollow mild steel pipe of 12.5 mm thickness and 250 mm length. The piston is made from 25 mm diameter mild steel rod which is in alignment with the center line of the cylinder bore. It slides in and out of the cylinder while the hydraulic pump is manually pumped. The lower end of the piston which makes contact with the workpiece has a larger diameter of 42 mm. The action of the piston causes either insertion or removal of force fitted assemblies. Two pieces of threaded stud of length 525 mm and diameter 20 mm were cut and four (4) nuts and spacer washers were screw to it (two on a stud) to hold the stud at both ends as shown in figure 1.
The force required to push and pull the piston is generated by a manually operated hydraulic pump. The pump has an arm which when moved up and down, releases hydraulic fluid into the hose to force the piston down. The hose helps overcome vibration and absorb hydraulic impulse shock. Hence, it is installed in such a way that there must be no twists. The workpiece support is a hollow rectangular beam with dimension 920 mm x 80 mm x 60 mm, welded to the sides of the frame (below the threads studs) for holding the workpiece while pushing or pulling operation is done on it. The support is adjustable to accommodate varying dimensions of workpieces by means of three (3) 17 mm diameter holes drilled on both sides of the frame.

2.4 Performance Test Procedure
To test the performance of the developed machine, seven bearings of bore diameters 24, 30, 40, 50, 65, 80 and 100 mm respectively were fitted into seven corresponding shafts with shaft deviation of ±0.001 mm and dismantled afterwards. The mounting and dismantling of the various bearing-shaft assemblies were done using three different methods: traditional hammering, using the developed manual hydraulic press and pull machine and using already existed electrically powered hydraulic press in each case. The time taken to mount and dismount the various assemblies for the three methods used was recorded. Also, the force required for press fitting the assembly was determined using equation 5 (NSK, 2008).

\[ F = \frac{1}{2} \mu E \pi B (1 - k^2) \Delta d \]  
(5)

Where:
\[ k = \frac{d}{D_1} = 0.7 \text{ to } 0.9 \]
\[ d = \text{nominal bearing bore diameter} \]
\[ D_1 = \text{raceway diameter of inner ring} \]
\[ B = \text{nominal inner ring width} \]
\[ \Delta d = \text{effective interference} \]
\[ E = \text{modulus of longitudinal elasticity} = 208 \text{MPa} \]
\[ \mu = \text{friction coefficient of the fitted surface} = 0.135 \]

The nominal inner ring width (B) for the various bore diameters were obtained from table 4.

Table 4: Nominal width for different bearing bore diameters (Khurmi and Gupta, 2006)

| Bearing bore diameter (mm) | Nominal inner ring width (mm) |
|---------------------------|------------------------------|
| 24                        | 15                           |
| 30                        | 19                           |
| 40                        | 23                           |
| 50                        | 27                           |
| 65                        | 33                           |
| 80                        | 39                           |
| 100                       | 43                           |

From table 5 above, press fitting force was determined (using equation 4) for bearing bore diameters of 24, 30, 40, 50, 65, 80 and 100mm as 337, 427, 517, 607, 742, 877 and 967N respectively. Hence, the force required to press fit a shaft into a bearing increases as the diameters of the shaft and bearing bore increase i.e., bigger shaft and bearings assemblies require larger press fitting force than smaller ones. Also, of the three methods investigated, it can be seen that traditional hammering is the most time consuming method of mounting and dismounting force fits, followed by the use of the developed press-pull machine. Electrically powered hydraulic presses are seen to be the most efficient (in terms of time conservation) for mounting force fits. Finally, with issues such as non-availability of electricity in local workshops as well as high cost of electrically powered hydraulic presses, the developed manual hydraulic press and pull machine is thus the best option for local workshops and artisans.

4 CONCLUSION
A manually operated hydraulic press and pull machine was produced using locally sourced materials. The strength of this machine was analyzed by simulating a load of 1000N and the corresponding values of maximum shear force, maximum bending moment and maximum displacement were determined as 74.9491N, 16.6335N.m and 4.367e⁻³mm. Also, maximum axial stress, bending stress and torsional stress where determined as 0.00359, 701998 and 0.00653N/m² respectively. The developed machine will bring relief to small and medium scaled workshops and artisans by reducing the time and stress associated with installation and removal of bearings, and other forms of force fits in machine assemblies.

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