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ORIGINAL RESEARCH ARTICLE

DEVELOPMENT OF A MANUALLY OPERATED SLEEVE PULLER KIT FOR RECIPROCATING TYPE ENGINE

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ABSTRACT

This work describes design and construction of manually operated sleeve puller kit for removal of piston liners. Piston cylinder sleeves which are firmly fixed in the engine block of many reciprocating engines are normally removed for the purpose of repairs, maintenance and replacement, and is difficult to remove by hammering; hence the need for a puller. To demonstrate the workability of the design, a cylinder sleeve of 100KvA generator was constructed. The components for the device were: frame, screw and base, constructed from grey cast iron, unalloyed free cutting steel and copper alloy materials respectively. The components were constructed using cutting, drilling, rolling and arc welding machine operations. The sleeve puller was tested on a 100KvA parkins generator. The cost of producing the device was N9, 150:00, which was effective compared to similar devices in the market that cost within the range of N15, 000 to N20, 000. From the performance test results obtained, the maximum torque to raise the required load was determined to be 452.898 × 103 N-mm and shear stress of the screw as 23.697MPa which was less than the strength of free cutting steel (56MPa). Buckling criterion was 371.09KN>75KN, transverse shear at the root and body area of the screw are 8.768<19MPa and 10.484MPa<56MPa. A piston sleeve puller was successfully developed. A hydraulic or electrically operated can further be investigate.

1.0 Introduction

Sleeve puller is bond to removal of piston liners of various kinds, particularly, to apparatus for removing the piston liners of internal combustion engines. During the active life of various engines, the pistons are constantly reciprocating up and down the cylinder and eventually the cylinder liner becomes scored, out of round, or so worn that compression is adversely affected and therefore, it becomes necessary to remove the cylinder liner and either replace the liner and the rings of the piston or grind and lap the bore of the cylinder liner and place oversized rings on the piston (Sarvana, 2017).

In the past, many researchers made some efforts to provide tools for removing sleeves of various kinds from internal combustion engines. However, in most of these prior art structures, it has been necessary to remove the piston before the mechanism for removing the cylinder could be attached (Krishnamoorthi et al., 2017). Due to space limitations, in most cases it has been necessary to remove the crank shaft from the engine before the piston could be removed. Therefore, the entire mechanism has to be disassembled before removing the cylinder liners (Krishnamoorthi et al., 2017).

The present research concentrates on the design and construction of a cost effective sleeve puller kit, for removable of internal combustion engine cylinder sleeves or liners for the purpose of repairs and maintenance. The work is limited to a sleeves diameter of 100mm to 150mm.

2. Methodology

2.1 Materials selection and design of machine components

The device comprises of three components; the frame, screw and the base.

FRAME: the material selected for the frame was FG200 (Graphite flakes Grey-Cast Iron with tensile strength of 200N/mm) which is in agreement with the work of Sarvana, (2017). The material has precipitate of carbon as 'graphite flakes which is soft in nature, and improves ability to resist compression load.

SCREW: the material for the screw was 'Unalloyed Free Cutting Steel' with composition of 0.25% carbon, 1.2% manganese, 0.14% sulphur. It has tensile strength of 56N/mm^2 with 10% elongation. Sulphur gives resistance to wear and 0.25% carbon gives it sufficient strength to compensate weakness in roots also easy in cutting due to manganese, this is in line with the work of Anand et al. (2015).

BASE: to ease replacement due to wear, either screw or the base material has to be soft, as screw is costlier than the base, phosphor bronze is the ideal material for the base, which is a copper alloy having 0.2% of phosphor which increase tensile strength. Ultimate tensile strength for this according to Khurmi and Gupta, (2012) is 19MPa, coefficient of friction is 0.1, with bearing pressure of 10MPa.

2.2 Methods

2.2.1 Design Analysis

The following considerations were made during the design:

a. The form and shape of the device is produced in a simplified manner.
b. The stresses and load bearing capacity.
c. The device efficiency, economy and availability of materials
d. The safety and durability of the device to be produced
e. Single thread screw was assumed for the design.
f. the screw is considered to be long coulomb

2.2.1 Screw Design:

According to Khurmi and Gupta (2012), for unalloyed cutting steel, assuming Core Diameter = d_c, Length = L = 360mm, sy_c = sy_t = Yield Strength = 1193.5 MPa

Compressive Strength (σ_c) is given as:

$$\sigma_c = {}^{1193.5}/_{5} = 238.7MPa$$

$$\sigma = {}^{W}/_{\frac{\pi}{4}} \times ({d_c}^2) \qquad (1)$$

$238.7 = {75000}/{\frac{\pi}{4}} \times (d_c{}^2)$

$d_c = 20mm$

Let d = Nominal Diameter corresponding to the cylinder bore diameter, p = Pitch, dr = Root Diameter, dm = Mean Diameter, l = Lead Screw, FOS = Factor of Safety: d = 55mm, p = 9mm, According to Khurmi and Gupta (2012), dr = 55 – 9 = 46mm>30mm and $d_m = d - 0.5p = 55 - 4.5 = 50.5mm$

Assuming screw has single start threads

l = p = 9mm

According to Khurmi and Gupta (2012), helix angle is obtained using the relation:

$$tan \propto = {l}/{\pi} \times d_m \ (rad) \quad (2)$$

$= {9}/{\pi} \times 50.5$,

$\propto = 3.2460 \ rad$

Coefficient of friction between screw and base, µ = o.1, considering bad lubricating conditions, assume µ = 0.18, according to Khurmi and Gupta (2012), the thread angle Ø isobtained from the relation:

$tan\emptyset = \mu = 0.18$

$\emptyset = 10.2039 > 3.0346$

Torque required to raise the load according to Khurmi and Gupta (2012) is calculated as:

$$T = W\left({d_m}/{2}\right) \tan \emptyset + \alpha \quad (Nmm) \quad (3)$$

$= 75 \times 10^3 \times \left({50.5}/{2}\right) \tan 10.2039 + 3.246$

$T = 452.898 \times 10^3 Nmm$

According to Khurmi and Gupta (2012), number of cross section of screw is subjected to addition of frame friction torque and base torque.

$$\tau_{ten} = {16T}/{\pi} \times d_r{}^3 \ (MPa) \quad (4)$$

$= {16 \times 452.898}/{\pi} \times 46^3$

$\tau_{ten} = 23.697MPa$

$\tau_{perm} = 56MPa > 23.69MPa$

The maximum tensile strength of free cutting steel (56MPa) is greater than the tensional shear stress of the screw. Therefore, according to Khurmi and Gupta (2012), the screw is safe in tensional shear stress.

According to Khurmi and Gupta (2012), using buckling criterion, when load was raised, the screw acted as coulomb, and there were chances of buckling or crushing, therefore, it must be decided whether the coulomb was long or short. Since one end of the screw was fixed and other was free, the end fixity coefficient was 0.52, and the Young modulus 207, 000MPa. Border line between short and long coulomb was;

$$syt/2 = \eta \times \pi^2 \times E / {1/k}^2 \quad (5)$$

$$560/2 = 0.25 \times \pi^2 \times 2007000 / {1/k}^2$$

$$1/k = 42.709$$

The length of the screw has to be greater than the length of the cylinder (360mm) in order to remove the liner, therefore, as reported by Khurmi and Gupta (2012), the length of screw considered is 550mm

$$K = \sqrt{I/A}\ (mm) \quad (6)$$

I = Inertia, K = Radius of gyration, A = Cross sectional area

$$I = \pi/4 \times {d_r}^4\ mm^4 \quad (7)$$

$$= 219.786 \times 10^3 mm^4$$

$$A = 1661.9925mm^2$$

$$K = 11.5\ mm$$

According to Khurmi and Gupta (2012), $Slenerdess\ ratio\ l/K = 550/11.5$

Slenderness ratio is more than critical slenderness ratio, therefore, screw is considered as long coulomb, hence using Euler's formula;

$$P_{cr} = \pi^2 \times E \times I / (1/k)^2\ (KN) \quad (8)$$

$$= 0.25 \times 207000 \times \pi^2 \times 1661.9025 / 47.826^2$$

$$= 371.09 > 75KN$$

2.2.2 Base Design:

According to Khurmi and Gupta (2012), the permissible bearing pressure between steel screw and bronze base is 10MPa, number of threads required

Given: pb = bearing pressure (MPa)

W = load applied (N)

Z = required number of threads

$$Pb = W \Big/ \frac{\pi}{4}\left(d^2 - {d_r}^2\right) \times z \;\; (MPa) \qquad (9)$$

$$10 = 75 \times 10^3 \Big/ \frac{\pi}{4}(55^2 - 46^2) \times z$$

Where $z = 10.50 \approx 11$

$H = Z \times P = 11 \times 9$

$H = 100mm$

Transverse shear stress at root of threads is given as;

$$\tau = W / \pi \times d_r \times t \times Z \; (MPa) \qquad (10)$$

where:

W = Axial load on the screw (N)
T = Torque (N.m)
d_r = root diameter of the screw (m)
Z = number of engaged threads
$\tau = 75 \times 10^3 / \pi \times 55 \times 4.5 \times 11$
$\tau = 8.768MPa < 19MPa$
The ultimate tensile strength (19MPa) is greater than the transverse shear stress at root of threads, therefore, base is safe in transverse shear at the root (Khurmi and Gupta, 2012).

Transverse shear stress at threads in screw is given by;

$$\tau = W / \pi \times d \times t \times Z \; (MPa) \qquad (11)$$

$\tau = 75 \times 10^3 / \pi \times 46 \times 4.5 \times 11$
$= 10.48MPa < 56MPa$
The tensile strength of free cutting steel (56MPa) is greater than the transverse shear stress at threads in the screw, making it safe in transverse shear stress at screw (Khurmi and Gupta, 2012).

$$\sigma t = W \Big/ \frac{\pi}{4} \times {D_o}^2 - {D_i}^2 \qquad (12)$$

where D_i and D_o are the inner and outer diameter respectively,

$$112 = \frac{75 \times 10^3}{\pi/4 \times D_o{}^2 - 55^2}$$

$D_o = 65mm$

By empirical relations

$D_o{}' = 1.3 \times D_o$

$= 1.3 \times 65 = 85mm$

The width of coulomb, considering shear failure,

$$\tau = W/\pi \times D_o \times T \qquad (13)$$

$19 = 75 \times 10^3/\pi \times 65 \times T$

$T = 20mm$

2.2.3 Component construction and assembly

The construction of three main parts of the device; frame, screw and base are described. Frame: a 5mm thick U-channel cast iron was used in the construction. Hacksaw was used for cutting and drilling machine was used to drill the hall, which was threaded using tap and wrench to accommodate the screw. The pieces were joint using electric arc welding (Figure 1).

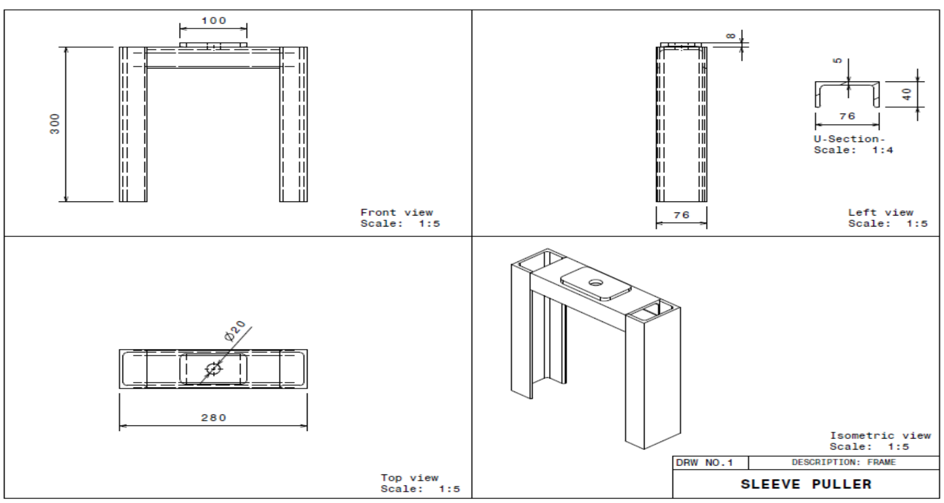

Figure1: Sleeve puller frame

Screw: threads were produced using cutting and rolling operations. The shank of the blank design for cut threading was full-sized from the fillet under the head to the end of the bolt. Measuring tape was used to measure the required size, and hack saw was used for cutting. The bolt blank was mounted on a lathe machine in order to produce the thread (Figure 2).

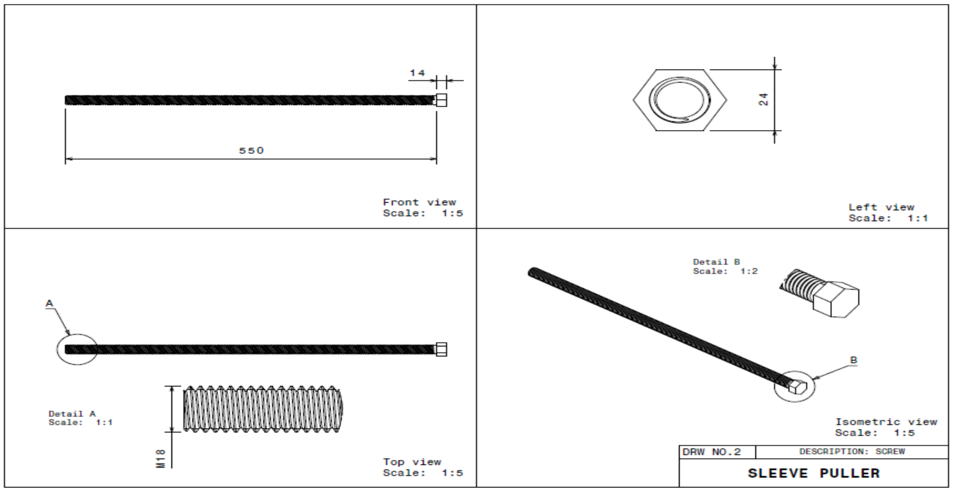

Figure 2: The Screw

Base: the base was made at the machine shop by using the cylinder sleeve measurements. The most important measurement was the outside diameter, it must be as close as possible to the block size and tight fit (Figure 3). The required hole was drilled at the centre of the base using a drilling machine and then threaded using tap and wrench (Khurmi and Gupta, 2012).

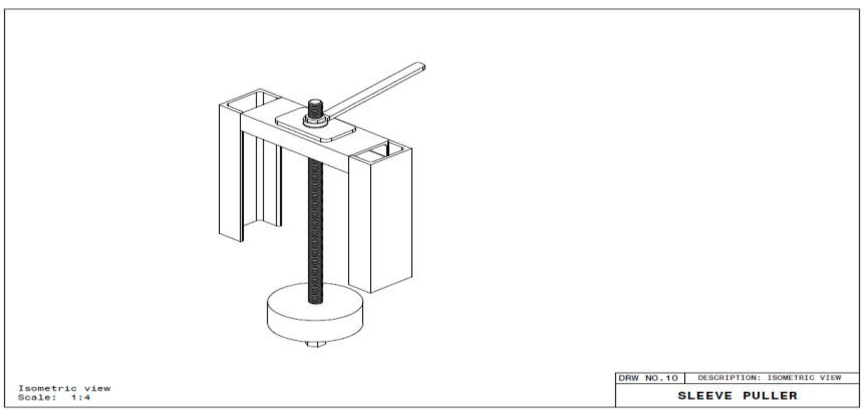

Figure 3 Assembled sleeve puller (Isometric view)

The efficiency of the device was calculated using the relation

$$\eta = {}^{work\ input}/_{work\ output} \times 100 \quad (14)$$

$where; work\ input = effort \times distance\ moved$

$work\ out\ put = load \times distance\ moved$ (Mohammed, 2021)

3.1 Bills of Engineering Measurements and Evaluation

The production cost is evaluated based on market prices of materials, the overhead and labour cost which is presented under section 3.1.1.

3.1.1 Analysis of Bill of Engineering Measurements

The material cost depends on the market prices, given in Table 1, as MC = ₦ 6, 100.00

Table 1: Prices of materials

S/No	Material	Size	Amount (₦)
1	Flat bar	750 x 100 x 10	2, 500.00
2	Blank bolt	600 x 30	2, 000.00
3	Flat plate	200 x 200 x 15	1, 000.00
4	Electrode	Gauge 12	6, 000.00
5	Total		6, 100.00

Direct labour cost was assumed to be 40% of the material cost from table 1, that is,

$$DLC = {}^{40}/_{100} \times 6100 = ₦\, 2440.00$$

Overhead cost was assumed to be 10% of the material cost;

$$OHC = {}^{10}/_{100} \times 6100 = ₦\, 6100.00$$

$$Production\ Cost\ CP = 610 + 2440 + 6100 = ₦\, 9150.00$$

From the market survey conducted so far, the price of similar device ranges from N15, 000 to N20, 000. This indicates the cost effectiveness of the present device.

3. Results and Discussion

The shear stresses and the buckling in screw were determined from the performance test carried out and compared with the maximum as shown in Table 2.

Table 2: Performance Test Evaluation

Tensional shear stress (MPa)	The screw in Buckling (KN)	Transverse shear stress at root (MPa)	Transverse shear area on the screw (MPa)
23.69	75	8.769	10.488
Maximum Tensional shear stress (MPa)	Maximum buckling in screw (KN)	Maximum Transverse shear stress at root (MPa)	Maximum Transverse shear area on the screw (MPa)
56	371.09	19	56

The performance test was carried out where iron sleeves provided a wear resistant surface for the piston rings supported by surrounding block. The iron sleeves have the same coefficient of expansion as the block, about 0.0015 to 0.002 of interference to be removed. The sleeve puller was firmly fixed on engine block and removal was successful, as shown in Figure 4.

Figure 4: A Piston removal using sleeve puller

The frame was placed at the top of the engine block to provide the necessary support to remove sleeves. A threaded rod (screw) was inserted through the centre of the frame at the top where a nut was attached (Figure 1). The sleeve was removed manually. A flange (the base) was attached to the sleeve at the bottom of the threaded rod (screw). When the rod was turned in clockwise direction, the sleeve was then removed successfully.

The torque required to raise the load was calculated using equation 3 as 452.898×10^3 N-mm and the shear stresses experienced by the screw and the base were calculated as

the tensional shear stress of the screw as presented in Table 1, was 56MPa>23.69MPa , hence the screw was safe in tensional shear stress. The buckling criterion was 371.09KN>75KN, hence the screw was safe in buckling. The transverse shear stress at the root of threads in base was 8.768MPa<19MPa, making the base safe in transverse shear stress at root. The transverse shear area on screw body was safe in transverse shear stress at screw.

Conclusion

The sleeve puller was successfully constructed, using the specified design considerations, from locally sourced materials. The sleeve puller was tested on a 100kva parkins generator.

The performance test was carried out where iron sleeves provided a wear-resistant surface for the piston rings, which were supported by surrounding block. The iron sleeves have the same coefficient of expansion as the block, so typically required about 0.0015 to 0.002 of interference to be removed. The sleeve puller was firmly fixed on engine block and removal was carried out successfully. The sleeve puller is an easy way of removing piston sleeves. The cost of the device, N9, 150:00, was effective when compared to similar devices in the market that range from N15, 000 to N20, 000 according to survey.

It can be modified hydraulically or electrically to reduce effort applied on pulling.

It can also be modified to serve dual purposes as a puller and presser.

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