Optimisation of Grease Dispensation for Heavy-duty Mining Excavators

Anthony Simons, Richard Wireko, and Cyrus Addy

Abstract—This work deals with improvement of the control of lubricant dispensation for automatic centralized lubrication system on heavy-duty mining excavators. The method adopted to achieve this includes analysis of mechanical, electrical and electronic components of the existing system. Subsequently, modifications were made on the system. Mechanical and electrical components were selected to control dispensation of lubricant whilst electronic components were selected to interact via communicating electrical signal to electrical components. Grease manifold block and current regulating solenoid valve were selected to work with a grease control module that communicates with a motion logic control module through a control area network connected to excavator joystick and pedal. Lubricant savings of $60.80 cm²/min (0.0608 litres/min) which amounts to annual savings of $62,102.09 per annum, can be made with the proposed modification in a typical mining excavator. The total cost of modification is $7,460.09 which about 7.40% of the savings that would be made from the proposed design.

Index Terms—Control Module, Dispensation, Joystick, Lubrication, Mining Excavator.

I. INTRODUCTION

In recent times, mining industries are facing a devastated ordeal of global downsizing due to low prices of all extractive minerals. Consequently, the industry is trying to reduce operating cost by curbing wastage at all facets of the mining activities and improve performance.

Mining excavators on the average consume as much as 5000 to 5500 kg of grease per month [1]. In fact, modern mining excavators have close to 100 lubricating points and consume about 110.05 cm³/cycle. The lubricating points are the joints for four coordinator kinematic movements: namely, boom, stick (crowd), bucket and swing gear and bearing.

The lubrication system of excavator starts operating when the engine of the excavator is switched on and the engine speed raised to nominal. Any deflection of the excavator joystick activates the centralised lubrication system to service all the kinematic movement joints or lubricating points with grease supply. This act does not take into consideration the fact that not all moving parts of the equipment would be effected or caused to move and therefore would not require any lubrication at that instant. More so, there is no need for continuous lubrication of a bearing, gear and pin or bushing of the excavator that has already been lubricated and is standing idle. Accordingly, there is over-lubrication and wastage of grease. The challenge now is how to lubricate only the components of the kinematic movement that has been deflected by the excavator joystick.

Researchers have done some works in this area. In fact, [2] sought to fix the cumbersome nature of automatic lubrication system by proposing a detachable automatic lubrication system for excavators. The works of [3] demonstrated a structure of automatic lubrication for slide mechanism. The patents of [4],[5] proposed a system for purging air in automatic lubrication system and flow confirmation system for the feed line of the lubrication system. Reference [6] presented a compact automatic lubrication system to be coupled to industrial machines and the system is triggered on by the movement of the machine. Reference [7] patented a computerized system to control the operations of lubrication system. The accredited works of [8] helped to correct the problem of time delay in boom assembly lubrication with a lightweight lubrication system. Furthermore, [9] presented a lubrication system for bearing assembly to provide accurate lubricant injection to bearings and extracting excess or used lubricant. These works pragmatically sought to improve the lubrication system. However, control of the dispensation unit of the lubrication system is still desirable. It is therefore imperative to come out with a design of lubrication system that considers savings on lubricant by supplying only to the components of the kinematic movement that have been deflected by the joystick.

II. EXISTING DESIGN

Mining excavators have two grease pumps P1 and P2 as shown in Fig. 1. Grease pump P1 is used for lubricating the pin and bushing of boom, stick and bearings of stick, bucket and swing components whilst grease pump P2 is for lubricating the swing gear of the excavator. Whenever the engine starts, the lubrication system is pressurized. Pressurized hydraulic oil from the pump PT drives the grease pumps when the three solenoids valves A1, A2 and A3 get energized by the grease control module. Grease is delivered through the feed line comprising of filter L, quick-coupler Q to grease manifold blocks K by the aid of pressure sensor J. The grease manifold blocks K have a number of mounted grease injectors H namely, 1 to 10 for boom, 11 to 23 for stick and 27 to 31 for bucket and two progressive blocks. The series progressive valve SSV12 is for the swing and pinion bearing, whilst, series progressive valve SSV14 is for swing gear bearing lubrication. The system works for a period of about 15 minutes for a complete cycle and then pauses for about 4 to 10 minutes settings depending on
operating, climatic and environment conditions.

It should be emphasised that, as long as the excavator engine is running and the operating time of the grease pump has not elapsed, the two greasing pumps P1 and P2 will be working to supply grease to all lubricating points. This does not depend on whether or not a particular implement (boom, stick, bucket or swing gear and swing bearing) is being utilized (moved), and thus requires lubrication. Movement of the implements are not closely monitored for the supply of grease. Indeed, the lubrication of all implements is not individually controlled and regulated.

A. Case Study

Data from three mining companies in Ghana were used in this work, namely Goldfields Ghana Limited, Newmont Ghana Gold Limited and Perseus Mining Limited. Table I depicts the technical details from four original equipment manufacturers (OEM) of excavators used in these mining companies and the type of lubrication system employed. The excavators commonly used are the mid-size excavators ranging from 200 to 400 tonnes with bucket sizes from about 12 to 22 cubic meters. Lincoln single-line Centro-Matic® grease system is used on these excavators.

In Table II, the load time and number of passes of bucket for the range of weight and bucket sizes of the excavators are depicted. These have been matched with truck payloads tonnage in Table I. Cycle times generally tend to increase with scale of equipment and difficulty of filling the bucket and varies between 2 to 18 minutes.

The magnitude of grease volumes of typical shovel-bucket-mining excavator having 82 greasing points is shown in Table III. The greasing points comprise of the excavator pins and bushings boom, stick and bucket, swing gear, swing ring bearing and gearbox bearing. Usually, one lubricating cycle is about 15 minutes and the total grease consumption of the greasing points is 110.05 cm$^3$ (0.11005 litres).
III. PROPOSED DESIGN

A research work was conducted at Accra Institute of Technology that led to a modification of the existing greasing system as depicted in Figure 1. The modified system has a grease manifold block M, regulating solenoid valves A for boom greasing, B for stick lubrication, C for bucket (flap) lubrication, D for Swing gear lubrication and E for swing bearing lubrication. In addition, an electronic grease control Module GC capable of communicating movement information of the boom, stick, bucket, flap and swing. This is achieved through Control Area Network (CAN) bus line together with Movement logic Control Module MLC, which is incorporated into the system.

The following components in the existing hydraulic circuit shown in Figure 1 remains unchanged in the modified greasing system as shown in Figure 2. These are the hydraulic pump PT, grease pumps P1 and P2, solenoid valves A1, A2 and A3, filter L, quick coupler Q, pressure sensor J, grease manifold K, grease injectors 1 to 36 mounted on their individual grease manifold block K and the progressive metering block 12 and 13.

With the proposed system, activation of the greasing system pump P1 and P2 will only take place when joystick JT is deflected and signal from the joystick reaches the Movement Logic Control Module MLC. The MLC, which manages the movement of the excavator (boom, stick, bucket, flap, swing and travel) sends corresponding motion signal through the CAN bus line to the grease control module GC.

Upon receiving a signal from the CAN bus line, the grease control module GC translates the movement signal into current signal depending on the angle of deflection of the joystick JT. This current signal is then sent to corresponding regulating solenoid valves A, B, C, D and E depending on the movement (boom, stick, bucket and swing) made by the Joystick JT.

The greater the angle of deflection, the faster the movement of the boom, stick, bucket and swing gear and bearing which subsequently requires larger volumes of lubricant. The regulating solenoid valves A to E have been synchronised with the speed of the movement by the Movement Logic Module MLC to release the required amount of grease to be dispensed when the speed of movement increases. Fig. 2 shows modified greasing system.

| Grease Pump (System) | Excavator Bearing Location | Greasing Point | Number of Greasing Points | Consumption per Cycle |
|----------------------|---------------------------|----------------|---------------------------|----------------------|
|                      |                           |                |                           | cm²/point Total (cm³) Sub Total (cm³) |
| P2                   | Swing Gear                | Gear Housing   | 32                        | 1.6 3.2 4           |
|                      |                           | 33             | 2                         | 0.4 0.8             |
|                      |                           | Top and Bottom of Swing Bearing | 34 35 | 0.83 1.32 10 |
|                      |                           | Pinion Bearing | 38 36                     | 0.18 0.35 0.35 |
|                      |                           | Boom           | 1                         | 0.66 1.32 5.28     |
|                      |                           |                | 2                         | 0.66 1.32           |
|                      |                           |                | 3                         | 1.32 2.64           |
|                      |                           | Boom Cylinder  | 4                         | 0.66 1.32 5.28     |
|                      |                           |                | 5                         | 0.66 1.32           |
|                      |                           |                | 6                         | 1.32 2.64           |
|                      |                           | Boom/Stick     | 7                         | 0.66 1.32 7.92     |
|                      |                           |                | 8                         | 0.66 1.32           |
|                      |                           |                | 9                         | 2.64 5.28           |
| P1                   | Attachment (Equipment)    | 10             | 2                         | 1.32 2.64 3.96     |
|                      |                           | Hoist Cylinder/ Boom | 12 13                     | 0.66 1.32 5.28     |
|                      |                           |                | 14                        | 0.66 1.32           |
|                      |                           | Boom/Shovel Cylinder | 16 15                     | 0.66 1.32 3.96     |
|                      |                           |                | 17                        | 0.66 1.32           |
|                      |                           | Stick/Bucket   | 18                        | 2.64 5.28 15.84    |
|                      |                           |                | 19                        | 2.64 5.28           |
|                      |                           | Stick Cylinder/Stick | 22 23                     | 1.32 2.64 3.96     |
|                      |                           |                | 24                        | 0.66 1.32           |
|                      |                           | Stick Cylinder/Bucket | 25 26                     | 2.64 5.28 15.84    |
|                      |                           |                | 27                        | 2.64 5.28           |
|                      |                           | Stick/Lever    | 28                        | 2.64 5.28 5.28     |
|                      |                           |                | 29                        | 2.64 5.28           |
|                      |                           | Bucket Cylinder/Lever | 30 31                     | 2.64 5.38 17.82    |
|                      |                           |                | 32                        | 3.63 7.26           |

TOTAL 82 Greasing Points 110.05 m³

TABLE III: GREASE VOLUMES NEEDED FOR OPERATIONS OF EXISTING MINING EXCAVATORS [12]
A. Selection of Grease Manifold

According to [13], a grease manifold was selected made of anodized aluminium with dimensions 30 cm x 4 cm x 4 cm based on the parameters in Table IV. Fig. 3 depicts the grease regulating solenoid valve.

Fig. 3: Grease Manifold [13]

| Parameter                          | Value                                                                 |
|-----------------------------------|----------------------------------------------------------------------|
| Type of Excavator                 | Mid-size to Large Mining Excavators (Eg. Liebherr R 9350)             |
| Manufacturer of Existing Manifold | Lincoln Centro-Matic                                                 |
| Type of Grease system             | Single-line                                                          |
| Size of Mounting Location         | 70 x 20 cm                                                           |
| Number of Manifold Outlets        | 5 outlet                                                             |
| Manifold Type of Material         | Anodized Aluminium                                                   |
| Maximum System Pressure           | 400 bar                                                              |
| Temperature of Grease             | -20°C to 60°C                                                        |

B. Selection of Grease Distribution Solenoid Valve

The current regulating solenoid valves A, B, C, D and E are two position valves with two port. The valve is a direct current valve, which opens depending on the magnitude of the energising current of the coil, which ranges from 100 mA to 1A. The valve body was selected based on relationship between the required solenoid force $F_s$, the grease pressure $P$, the valve orifice area $A$ and diameter, $d$. Using the selection criteria in Table V, based on the design of the greasing system, soft iron regulating solenoid valve with manually activated lever and copper coils was selected from [13]. In addition, the specifications of the distribution solenoid valve are depicted in Table VI.

Fig. 4: Grease Distribution Solenoid Valve [13]
The essence of this work is to curb the wastage in grease usages in the operation of the excavator. After modification of the existing greasing system, it is imperative to compute for the envisaged savings in grease dispensation. Table VII shows the four stages of operation in mining excavator cycle when loading a dump truck that has been modified after [14].

### IV. RESULTS AND DISCUSSION

#### A. Results

This section considers the quantity of grease saved and the subsequent economic gains upon modifying the greasing system of the mining excavator.

1) **Quantifying the Grease Savings**

The essence of this work is to curb the wastage in grease usages in the operation of the excavator. After modification of the existing greasing system, it is imperative to compute for the envisaged savings in grease dispensation. Table VII shows the four stages of operation in mining excavator cycle when loading a dump truck that has been modified after [14].

The four stages are waiting (idling), digging, swing to dump or swing back to dig and dumping of bucket load. During waiting, the excavator joystick JT is released or untouched by the excavator operator. The regulating solenoid valves A, B, C, D and E are not energised, consequently, the lubricating system stops to release grease to the lubricating points. Assuming an average excavator standby time of 1.5 minutes, the estimated amount of lubricant saved for 15 minutes lubrication system cycle is:

\[ \frac{1.5}{15} \times 110.05 = 11.01 \text{cm}^3 \]

Consider using the R 9350 Liebherr excavator and a truck of 250 tonnes payload in the computation process, then from Tables I and II bucket capacity of 18 m³ is needed to load the truck. This will require four (4) bucket passes with loading time of about 8 minutes. During digging operation, the boom, bucket and stick motions are used simultaneously in filling the bucket with loads. Solenoid valves A, B and C are activated. No swing movement is required. The average implement motion time of 10 seconds is needed as shown in Table VIII [15].

Therefore, if in digging operation, every implement performs an extension and retraction motions then in all, the time for a pass (process) would be 60 seconds.

Accounting for the duration of the four passes: 1 minute x 4 passes = 4 minutes. The lubricant consumed is estimated as:

\[ \frac{4}{15} \times 121.06 = 32.28 \text{cm}^3 \]

Subsequently, swing to dump and swing back operations activates solenoid valves D and E. This operation takes...
about 32 seconds (Table VIII). The lubricant consumes during this operation is:

\[ \frac{32 \times 4}{15 \times 60} \times 121.06 = 17.22 \text{cm}^3 \]

In excavator dumping operation, only bucket motion is required and only solenoid valve C is energised. This operation takes about 20 seconds (Table VIII). The estimated grease consumed is:

\[ \frac{20 \times 4}{15 \times 60} \times 121.06 = 10.76 \text{cm}^3 \]

| TABLE VIII: EXCAVATORS IMPLEMENT MOTION TIME [15] |
|---------------------------------------------------|
| Implement Motion     | Boom | Stick | Bucket | Swing (per 3.7 revolution) |
| Duration (Seconds)   | 8 - 12 | 7 - 10 | 6 - 10 | 7 - 11 | 6 - 10 | 7 - 11 | 16 | 16 |

Tables IX and X detail the grease savings and its monetary estimation after modifying the greasing system.

| TABLE IX: ESTIMATION OF GREASE SAVINGS |
|---------------------------------------|
| Excavator Joints Utilized             | Lube Points | Consumption per Cycle (cm³) | Waiting (Idling) | Digging | Swing to Dump | Swing to Dig | Dump to Truck |
| Gear Housing                          | 32           | 4                             |                 | 4       | 4             |
| Top and Bottom of Swing Bearing       | 34           | 10                            |                 | 10      | 10            |
| Pinion Bearing                        | 36           | 0.35                          |                 | 0.35    | 0.35          |
| Boom                                  | 1            | 5.28                          |                 |         | 5.28          |
| Boom cylinder                         | 4            | 5.28                          |                 |         | 5.28          |
| Boom/Stick                            | 18           | 7.92                          |                 | 7.92    | 7.92          |
| Boom/Stick Cylinder                   | 10           | 3.96                          |                 | 3.96    | 3.96          |
| Hoist Cylinder/Boom                   | 12           | 5.28                          |                 | 5.28    | 5.28          |
| Hoist Cylinder/Boom                   | 13           | 5.28                          |                 | 5.28    | 5.28          |
| Boom/Stick Cylinder                   | 15           | 3.96                          |                 | 3.96    | 3.96          |
| Stick/Bucket                          | 18           | 15.84                         |                 | 15.84   | 15.84         |
| Stick Cylinder/Stick                  | 20           | 3.96                          |                 | 3.96    | 3.96          |
| Stick Cylinder/Bucket                 | 22           | 15.84                         |                 | 15.84   | 31.68         |
| Stick/Lever                           | 24           | 5.28                          |                 | 5.28    | 5.28          |
| Stick/Connect-ing Link                | 26           | 5.28                          |                 | 5.28    | 5.28          |
| Bucket Cylinder/Lever                 | 28           | 17.82                         |                 | 17.82   | 17.82         |
| Total Grease Consumption for various operations | 11.01 | | | 11.01 | 110.05 |
| Total Grease Consumption without Modification (A) | 11.01 | | | 110.05 | 121.06 |
| Actual Consumption with Modification (B) | 32.28 | | | 17.22 | 10.76 | 60.26 |
| Grease Savings Made                   | A – B = 121.06 – 60.26 | 60.80 |

| TABLE X: MONETARY ESTIMATION OF THE GREASE SAVINGS |
|---------------------------------------------------|
| Quantity of Grease Savings per Cycle (15 minutes) (l/min) | Quantity of Grease Savings per hour (l/hour) | Quantity of Grease Savings per 20 hours/day (l/day) | Amount of Grease Savings per 20 hours/day ($) | Annual Grease Savings (365 days in a year) ($) |
|---------------------------------------------------|
| 0.06080                                           | 0.06080 × 4 = 0.2432 | 0.2432 × 20 = 4.864 | 4.864 \( \div 170.1427 \times 0.5 \) | 170.1427 × 365 = 62,102.09 |

According to [16], the price of 0.5 litre NLGI multipurpose Lithium grease is $17.49. It could be seen from Table X that the quantity of grease savings per day is 4.864 litres that amounts to $170.14 per day that subsequently translates to approximately $62,102 per annum.

2) Cost of Modification of Greasing System

The total cost would comprise of the cost of components, production lost and labour.
3) Cost Due to Lost Production

The cost due to production lost is computed in Table XI.

| Parameters          | Excavator R 9350 |
|---------------------|------------------|
| Bucket Size         | 18 m³ / 34 tonnes|
| Production per hour (Assuming loading 250 tonnes truck in every 5 minute) | 60 / 8 = 7.5 m³ / hour |
| Average cost of mining | $ 5.927 /tonnes  |
| Lost Productivity Per Hour | 1875 = $316.35 per hour |
| Lost Productivity in 3 hours | 3 x 316.35 = $949.05 |

4) Cost of Components

a) Cost of Selected Solenoid Valve

According to [13], the unit price of item number 161-110-031, a normally closed solenoid valve is 608.81 Euros, based on the specifications of Parker Lucifer solenoid valve in Table V and VI. There are five (5) solenoid valve required, therefore, 5 x 608.81 = 3044.05 Euros, which is 3603.41 US dollars [20] (as at 7th August, 2020).

b) Cost of Selected Grease Manifold

From [13] and [21], the unit price of the selected grease manifold, 325-861, SKF – 5 ports; d”M10x1 –d’ 5X M10x1 (VR05GAM3) is 13.98 Euros, which 16.55 US dollars [20] (as at 7th August, 2020).

c) Labour Cost

According to [22], the average hourly labour rate of technician is 16.93 Ghana cedis and that of an engineer is 21.19 Ghana cedis as shown in Appendix E. Assuming two (2) technicians and an engineer were to install the proposed greasing system in three hours. The labour cost would be 2(16.93 x 3) + (21.19 x 3) = 101.58 + 63.57 = 165 Ghana cedis and this is equivalent to 28.40 USD [20] (as at 7th August, 2020):

The total cost of installation therefore would be 3603.41+16.55 + 28.40+949.05 = $4,597.41

The total cost of modification is only 74.0% of the savings that would be made from the proposed design.

B. Discussion

Figs 5 and 6 give a conceptual view of the new design having machine movement joystick, movement control module, communication line, grease control module, voltage solenoid valves for a grease pump, grease manifold block and regulating solenoid valves A, B, C, D and E. The excavator is equipped with a joystick for deflecting movement of implement such as the boom, stick, bucket and swing. The movement logic control module is an electronic control module programmed to receive low electronic signals from the joystick and the pedal. These signals are amplified into a form that can activate solenoid valves for movement. As such, this electronic movement signal is converted by the translator into a frequency that is then relayed onto a communication line for other electronic module such as the grease control module to access from the network. Fig. 5, shows conceptual module of the proposed greasing system and Fig. 6, program flow chart for the proposed greasing system.

The translator of the grease control module converts back the frequency of motion signal into current. The grease control module then amplifies this current signal from 100 milli-amperes to 1 ampere depending on the joystick deflection. The current signal is sent to the respective current regulating solenoid valve (A for boom, B for stick, C for bucket, D for swing gear bearing and E for swing ring bearing). The opening of the solenoid valve depends on the magnitude of the current which passes through the valve to the grease injectors and thus determines the amount of grease to the lubricating points.

Optimization of the grease dispensation is achieved in part by the start-up of the lubrication pump only when the joystick JT is touched or deflected, and by regulating the amount of grease that is to be let out by the solenoid valves.

The flow chart (Fig. 6) shows the step-by-step progression of command from the joystick JT to the regulating solenoid valve to release the exact amount of grease needed for the lubrication at a particular implement.
V. CONCLUSION AND RECOMMENDATION

The control of lubricant dispensation of the existing grease system of the mining excavator is optimised by modifying the design to incorporate a grease manifold block and current regulating solenoid valve which is linked to a grease control module. The grease control module communicates through a control area network with the aid of a movement logic control module that is connected to excavator joystick and pedal module.

Evaluation of the excavator operational cycle with the design modification gave the quantity of grease savings to be 4.864 litres per day, which is equivalent to approximately $62,102 per annum. Also, the implementation of the new system costs a paltry $4,597.41, which is 7.40% of the savings per annum. Further studies should be done in the area of programming of the speed of the Control Area Network (CAN).

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