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REMANUFACTURING, AN UNTAPPED RESOURCE FOR PRODUCTIVITY IMPROVEMENT

By

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DECLARATION

1. I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another award to the Kwame Nkrumah University of Science & Technology or elsewhere.

……………………………………………….

Michael Kwasi Asafo-Adjaye

2. I hereby declare that the preparation and presentation of this Thesis was supervised by me at the Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, and that it is the candidate's own work.

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Dr. Yesuenyeagbe A. K. Fiagbe

CERTIFICATION

I certify that this thesis has been assessed and all corrections have been made in accordance with the comments made by the examiners.

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DEDICATION

To the Glory of God the Father who gave me the strength, direction and determination to complete this work.

A second dedication to my wife Gloria, children Michael Jnr. Adelaide and Aaron whose encouragement gave me the inspiration to move on in spite of the challenge of combining my hectic job schedule with this work.

ACKNOWLEDGEMENT

I am sincerely grateful to God for His love and mercy and for the wisdom and direction offered me in completing this work successfully. Special thanks to my colleagues Ahmed Andoh and Isaac Adusei Twumasi for their tremendous assistance.

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To all of you I say God richly bless you.

ABSTRACT

Currently in Ghana, no opportunities have been identified in the open market where one could purchase a used part (e.g. an engine or gear box) and be assured of properly documented warranty or customer satisfaction guarantees. The aim of this project therefore, is to investigate the potentials of remanufacturing with the view to illustrate the potential economic, environmental and social benefits associated with the practice.

The findings of this research indicates that approximately 87,400,976.80 kilograms of used spare parts notably used engines, drive axles and differentials, used radiators, gear boxes etc. were imported into the Country between 2005 to 2010 to be used on 'as is basis'. During the same period, GH¢30,822,609.06 was generated as other taxes for the government, apart from a total of GH¢50,252,918.32 generated as import duty. It was also noted that approximately forty eight thousand units of used engines are imported into the Country each year. Getting value for money out of the patronage of these components is by chance. This is so because facilities and systems for rebuilding them to such high standards are currently not available in the Country. It is only a few heavy equipment companies like Caterpillar that are remanufacturing for their clients in the heavy equipment industry.

It is realized that there is adequacy of cores to be used for remanufacturing in Ghana and eleven African Countries are already in the practice. Some of these Countries are South Africa and Kenya which are into automotive and engineering remanufacture as well as Botswana and Nigeria that run Microsoft Authorized Remanufacturing facilities, creating better economies and enhanced standard of living for their people. Ghana can tap into this hidden economic prospect and be part of this evolving trend in Africa.

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CHAPTER ONE

1.1 INTRODUCTION

Ghana as a developing nation has been involved in the importation of used machinery, parts and equipment. These machinery and equipment vary from decommissioned facilities to automobile spare parts. The situation is such that, in the area of automobiles, large deposits of used parts are seen in 'spare part shops' in most parts of the country. The situation is clearly seen at Suame magazine in Kumasi and Kokompe in Accra where lots of used machinery and automobile parts are deposited for sale on arrival into the country. It can be said that lack of manufacturing facilities to produce machinery and automobile parts has largely contributed to this situation. The usual practice is the sale of the used equipment or component on 'as is' basis without any warranties or customer satisfaction guarantees. In some instances, one could be lucky to get some form of short period guarantee or warranty. These assurances in most cases do not work and when there is an actual problem with the usage or the component fails to work, a customer might end up not getting his or her investment back. For example, an engine that is sold in the magazine area or Kokompe can only be tested either on the ground or on the chassis after installation, in most cases, on the chassis. These tests are usually physical observation for leakages and sound quality. No standard or technical procedures are used in testing these products for quality. Used or junkyard components might have had high usage or poor maintenance history which could be an indication that failure could happen unexpectedly. Some of these used components may come from a vehicle involved in an accident and may have undetected damage. Despite all these challenges, patronizers of used components in Ghana are increasingly becoming interested in components that have not been tampered with when imported because there is a growing lack of confidence in the ability of artisans and mechanics to remanufacture these components locally to acceptable standards. This can be attributed to evolving new technologies and a lack of exposure of these artisans to these new technologies. This seemingly growing trend signifies the widening gap that is being created by the absence of remanufacturing.

1.2 STATEMENT OF PROBLEM

Currently, Ghana cannot boast of a facility or shop where one can walk in and buy a remanufactured engine, remanufactured minor or major component or equipment with warranty or properly documented customer satisfaction guarantees. Even though a company like Caterpillar (Mantrac) does some remanufacturing locally, it is limited to its own clients, mainly the mining companies, and other patronizers of their products. Lack of local investment in remanufacturing could be attributed to the fact that much awareness has not been created about the potentials it has to stimulate industrial growth and to satisfy the general quest for quality re-useable parts in the country. With Ghana gradually entering into the middle income status, people will be happy to spend more and have value than to buy products whose quality cannot be guaranteed. This is the current situation which will be investigated in this research.

1.3 OBJECTIVES OF RESEARCH

The objectives of this research are to investigate the potentials of remanufacturing and illustrate the potential economic, environmental and social benefits associated with the practice.

1.4 SPECIFIC OBJECTIVES

Specific objectives of this research include the following;

1. Investigating the process for remanufacturing a product for example an engine, examine all the processes involved from strip down to re-assembly and testing and make the necessary comparisons between this remanufactured product and a used engine purchased on 'as is basis' and the benefits to be derived thereof.

2. To demonstrate the potential socio-economic benefits to be derived from the introduction of remanufacturing into the country.

3. To demonstrate how the introduction of remanufacturing will help reduce the incidence of waste 'cores 'in the system.

1.5 JUSTIFICATION

1. A survey conducted round the Suame magazine and Kokompe spare parts and mechanics shops in Kumasi and Accra showed brisk used spare parts business.

During the survey, it was observed that no well-established mechanic shops where proper remanufacturing is being done was identified. It was evident then that there was a general lack of awareness of the existence of remanufacturing among the artisans. This was generally perceived as impossibility in a third world country like Ghana.

2. Every stage in the remanufacturing process involves skilled and unskilled labor, from disassembly, cleaning, inspection, through parts re-conditioning until assembling and final testing. Hence remanufacturing has the greater potential to stimulate growth and create skilled and unskilled jobs.

It is a unique strategy for business development and creation of jobs which will eventually enhance the socio-economic development of our Country.

3. By remanufacturing a used 'core', one will be adding more life cycles to the product beyond its first life and reducing the environmental impact of an inert core lying on a landfill. This can turn around costly disposal processes into product loops and secure a sustainable future for our environment.

1.6 METHODOLOGY

The methodology includes data collection on the importation of used parts into the Country. There is also a case study of the remanufacture of an engine from strip down to assessment, re-conditioning of re-useable parts, criteria for replacement of parts, re-building and dynamometer testing to original equipment manufacture's specifications. Through this methodology, the technical details of what is meant by remanufacturing and what needs to be done to a used component usually referred to as the 'core' to have it remanufactured to the original equipment manufacturer's specifications is presented.

1.7 FACILITIES AVAILABLE FOR RESEARCH

1. Caterpillar (Mantrac) workshop in Tarkwa and Kenyase.
2. Suame Magazine Industrial Development Organization (SMIDO) workshop and office in Kumasi.
3. Customs Division, Ghana Revenue Agency database in Accra, for collation of data on importation of second hand parts into the Country.
4. Internet.

CHAPTER TWO

LITERATURE REVIEW

2.1 DEFINITION OF REMANUFACTURING

Remanufacturing is a legitimate commercial practice. It is a process whereby a worn out, discarded or used product usually referred to as the 'core' are recovered from commercial usage and transformed into new products to be re-introduced into the stream of commerce. The result is a product that is tested and certified to meet the original or current technical and /or safety specifications of the product [1]. The process involves the disassembly, cleaning, inspection, functional testing, re-conditioning or replacement of worn parts, re-assembly and quality assurance testing of the assembled core to specifications similar to that of a new one [2]. The remanufactured product can be sold with warranties, customer satisfaction guarantees and /or maintenance contracts similar to that of a new product. It seeks to retain the value inherent in the core and sometimes often adds more value to it in terms of software upgrade [1, 2]. Remanufacturing is also described as a process whereby a worn out or discarded product is completely disassembled, parts cleaned, inspected, refurbished, or replaced as necessary and product reassembled to perform like new [3]. Remanufacturing employs less labor, energy and materials in comparison to the manufacture of a new product [4]. In the United States of America, there are 70,000 firms involved in remanufacturing with the major sectors being the automotive industry, machinery, office equipment, tires, toner cartridges, valves and many more. Here, the automotive industry leads in terms of the number of firms with the industry employing over 480,000 people directly and indirectly with annual sales of remanufactured products at 53 billion United States dollars.

Remanufacturing leads to materials, plant/equipment and energy conservation. It is a good source of employment generation and industrial skills training [5, 6, and 7]. Worn parts are reconditioned or replaced where necessary before it is reassembled. It uses the existing products recovered from commercial use as inputs, providing an opportunity for material and energy savings in the production process. These remanufactured parts are generally sold retaining the value inherent in the core and often adds further value to it [8]. Remanufacturing begins with the reclamation of the used durable products, (cores).These products are then disassembled into parts, which are cleaned, inspected, and tested to determine whether they meet acceptable quality standards to be reused. Some parts become waste; others that do not meet standards can be repaired or reconfigured. These used parts and some new ones are then combined to reassemble the original core from which they are reclaimed, or to build a product with a new identity. Remanufactured products typically have the same performance characteristics and quality standards as new ones. A successful remanufacturing operation adopts high quality standards. It allows offering products that enhance brand equity and keep customers loyal. In the United States of America, remanufacturing has been around for over sixty years restoring old products to the performance of new ones, thus saving energy, natural resources, landfill space and reducing air pollution by less re-smelting. This industry also creates hundreds of thousands of jobs and new tax paying businesses.

By extending product life and giving products numerous lives, remanufacturing saves 85% of the energy that went in to manufacturing the product the first time [2, 3, 6, 9]. Jasper Engineering in California was started in 1942 and has grown from a family owned business to become one of the largest private sector employers in its branch in Indiana. This company also has 1580 associates with forty one (41) branch and distributor locations in the United States of America. Jasper produces totally remanufactured components like engines and transmissions to meet or exceed original equipment manufacturer (OEM) specifications and tolerances, thoroughly tested to ensure quality, reliability and satisfaction with warranties up to 3 years or 100,000miles. It is the United States largest remanufacturer of diverse lines of drive train products. Annual production includes over 117,500 gas and diesel engines, transmissions, differentials and rear axle assemblies [9]. Remanufacturing not only promotes the multiple reuse of materials, but it also allows for the steady upgrading of quality and functions of products, and does this without the need to manufacture completely new products and throw away used ones. It brings used products to 'like new' functional state with warranty to match. It recovers a substantial proportion of the resource incorporated in a used product in its first manufacture, at low additional cost, thus reducing the price of the resulting product. It is a process of returning a used product to at least (OEM) original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured product [3, 4, 5, 6, and 7]. Remanufacturing could be targeted at total life cycle management[8] where the product can be recycled and re-used at again after the first manufacture to save the environment, create skilled jobs and produce high quality goods at relatively lower prices than the new one.

2.2 DIFFERENCES BETWEEN REMANUFACTURING, RECONDITIONING, REPAIR AND OVERHAUL

Even though the processes involved in remanufacturing, reconditioning, overhaul and repair appear to be similar, a clear difference exist between remanufacturing and all the other processes on a hierarchy based on the work content that they typically require, the performance that should be obtained from them, and the value of the warranty they normally carry. The differences in these processes are as explained in Table 2.1.

2.3 BENEFITS AND CHALLENGES TO REMANUFACTURING

The benefits associated with remanufacturing cannot be over-emphasized. It ranges from *business enterprises, environment and economic benefits breaking down to employment generation and skills development*. These benefits far outweigh the challenges that are associated with remanufacturing which is usually synonymous with the introduction of any new business enterprise.

TABLE 2.1: Differences between Remanufacturing, Overhauling, Rebuilding and Reconditioning

ACTIVITY	WORK CONTENT	PERFORMANCE	WARRANTY
Remanufacturing	Greatest degree of work content. All parts have to be reconditioned/replaced and tested and where possible upgraded to or above original equipment manufacturer's specifications.	Performance of a remanufactured component normally expected to be in line with OEM specifications and perspective.	A Remanufactured component can have warranties up to 100,000 miles or 3 years whichever comes first usually similar to that of a newly manufactured product or alternative. It is a standard requirement.
Overhaul/Rebuilding /Re-conditioning	Some high degree of work content required but not to the level of a remanufactured component and more than repair. Could be inferior to the original specification.	It is expected to meet customer's expectations but not expected to meet equipment manufacture's specifications.	Warranty on an overhauled/rebuilt/re-conditioned part not a standard requirement/obligatory. Warranty may apply only to wearing parts.
Repair	Lower work content as correction is normally specified to faults in a product.		Repair warranty less than those of newly manufactured products, usually covering only the component that has been replaced/ repaired.

Source: Guintini R, Gaudette K (2004), www.reman.org

2.3.1 BUSINESS ENTERPRISES

Caterpillar, a global giant in the heavy equipment industry, defines remanufacturing as a total life cycle management. It has been in the business of remanufacturing for over thirty (30) years. Caterpillar has generated 44.9 billion in sales distribution to more than 200 Countries in 23 time zones all over the world with over 300 facilities in

40 Countries including Africa. Its remanufacturing business employs a little over 6,000 employees and has 15 primary facilities for remanufacturing in 8 Countries all over the world. In 2007 it produced 2.2 million remanufactured units for it's over 181 dealers worldwide. A core returned in good condition generates up to 40% credit on a sale as compared to a non-core return sale. The policy of Caterpillar is to target zero landfill status [10]. This means to reduce the environmental impact of an inert core lying on a landfill by zero percent as options are being considered to send scrapped metals that cannot be remanufactured to their own foundries. Many companies especially in the United States of America are incorporating remanufacturing into their corporate strategic vision. General Electric is one such example where their stakeholders are seeing greater growth and stability in their investments [11]. Remanufacturing is proving to be a profitable business field as many companies in Europe and North America are making significant profits by selling remanufactured products and components e.g. mobile telephones and automobile components, mainly in emerging markets [12].

2.3.2 ENVIRONMENTAL BENEFITS

Referring to remanufacturing as an untapped resource for productivity improvement, one is comparing input to output. In other words, by adding more life cycles to a product beyond its first life, one will be increasing the productivity of the component, increasing the output with less input, compared to the case without remanufacturing, reducing the environmental impact of an inert core lying on a landfill and conserving the environment. Remanufacturing produces less greenhouse gases, less raw material use, less landfill waste, less energy and water use whereas promoting extended producer responsibility and, creating more jobs and sometimes product upgrades [13]. It is therefore good for the society, good for business and good for the environment.

Remanufacturing does not require the same material and energy inputs compared to original manufacturing. It has been estimated that remanufactured goods conserve the equivalent of 400 trillion British Thermal units (BTU) of energy per year. This is accomplished by saving 85% of the energy required to produce a new one. As an indication of the impact that conservation through remanufacturing is having, the 400 trillion (BTU) of energy saved is enough to power 6 million passenger vehicles each year. The raw materials saved would fill 155,000 railway cars in a train spanning 1,100 miles [14]. Remanufacturing results in a reduction of solid waste that is produced by the disposal of decommissioned equipment and their spare parts inventories [15]

2.3.3 ECONOMIC BENEFITS

Remanufacturing is a hidden giant [9]. The types of products that can be remanufactured vary, generally falling into two main categories, capital goods and consumer durable goods. Capital goods can be anything from complex military weapon systems to manufacturing, mining, agricultural equipment to vending machines. They constitute a majority of remanufacturing expenditures in countries like the United States of America. Large scale remanufacturing of consumer durable goods like computers, laser toner cartridges and cameras are still in the infant stage due to the process costs which are sometimes unattractive limiting their use in industry [11, 16]. The impact of capital goods remanufacturing on the US economy is shown in Table 2.2

TABLE 2.2: Size and Scope of Remanufacturing activity in the USA

IMPACT OF CAPITAL GOODS ON US ECONOMY	
Total number of firms	73,000
Total annual industry sales	$53 billion
Total direct employment	480,000
Average annual company sales	$2.9 million
Average company employment	24
Number of product areas	Over 46 major categories

Source: Lund (1996)

The impact of remanufactured consumer durable goods on the US economy is shown in Table 2.3

TABLE 2.3: Relative Size and Scope of Remanufacturing activity in the USA

INDUSTRY SECTOR	EMPLOYMENT	SHIPMENT VALUE
Remanufacturing	480,000	$53 billion
Household Consumables	495,000	$51 billion
Steel Mill Products	241,000	$56 billion
Computers & Peripherals	200,000	$56 billion
Pharmaceuticals	194,000	$68 billion

Source: Lund (1996)

Due to the fact that remanufacturing does not have the same material requirements as original manufacturing, it is considerably less expensive.

Generally, the cost of a remanufactured product is about one third (1/3) to one fourth (1/4) of that of the original product. In addition to the savings resulting from material difference, there is less cost in terms of site preparation and construction costs [11, 16]. This is further illustrated by table 2. 4.

TABLE 2.4: Cost Comparison between Remanufacturing & Manufacturing using Breakers

ECONOMIC COMPARISON REFURBISHED VS. NEW CIRCUIT BREAKER.		
	Refurbished Breaker	New Breaker
Prep./Site construction Work (using same foundation)	N/A	16 Man days at $60/hour, $7,680.00
Engineering	N/A	10 man days at $60/hour, $4,800
Disposal of Breaker Carcass	N/A	$3,000
Refurbishment	$75,000	N/A
Installation test	$37,500	$65,000
New Product	N/A	$200,000 to $300,000
Spare Parts	N/A	$3,000
Raining	N/A	5 employees at $1,600 each, $8,000
TOTALS	$112,500	$291,480 to $391,480

Source: McCracken A, Christiansen R, 1998, www.reman.org.

Most remanufactured products (e.g. cartridges) are 40 to 60% cheaper than the original equipment manufacturer's cartridges with comparable quality and reliability.

In fact many remanufactured cartridges last longer as they can have up to 20% more toner than OEM cartridges [5, 16, 17].

2.4 CHALLENGES TO REMANUFACTURING

Potential major challenges to remanufacturing have been identified to include the following: *Employee skills, Product Diversity, Availability of replacement parts, Warranty Returns, Market Acceptance, Logistics & after-sales Support.*

2.4.1 PRODUCT DIVERSITY

This also refers to part proliferation and it describes the practice where for example the Original Equipment Manufacturer (OEM) produces multiple unique models of the same part for a given car line, or by changing aspects of the part (making it unique) on a frequent basis, perhaps even more than once per model per year [18]. Problems arising from this practice range from having to keep a large inventory of replacement parts, to having to keep track of several, non-standardized assembly and disassembly processes. An increase in the variety of assembly and disassembly processes also results in an increase in the number of process set-ups that have to be made, causing a reduction in throughput. Employee training also becomes a significant issue as a result, as they must be familiarized with all of the various unique parts and the processes for each new product [18].This poses a major challenge to the process and efforts will have to be made to manage this challenge as it cannot be eliminated.

2.4.2 EMPLOYEE SKILLS

Employee skills are predominant in three separate major categories of the remanufacturing process, notably inspection, refurbishment and reassembly. This is primarily due to the diversity of unique products which the employee must be familiar with. The different assembly and disassembly techniques required for each and the ability of the employee to identify which quality standards the specific part must measure up to. In this regard, skill is followed by specification availability which is mostly not available from the manufacturer as a result of which some remanufactures rely on experience [18]. Employee skills are a challenge which cannot be eliminated but could also be managed. A continuous improvement approach to the process will factor in these challenges and as they arise, efforts will be made to mitigate them.

2.4.3 AVAILABILITY AND COST OF REPLACEMENT PARTS

It is a major issue which is strongly linked to product diversity and part proliferation and a lack of cross referencing for aftermarket supplier's (wrong adulterated parts) which are usually not catalogued. Having to import most of the parts because they are not manufactured locally, will in the long term, result in a higher cost of replacement spare parts. The best approach to remanufacturing is to have a collaboration /partnership with the Original Equipment Manufacturer (OEM) for the supply of inputs in terms of employee training and spare parts. The use of OEM tolerance specifications and spare parts instead of aftermarket parts (non-genuine parts) will improve the remanufactured component's quality. Replacement parts will be more available which will result in a high quality end product [7, 18]. In the light of the above, it is always advisable to use OEM parts instead of aftermarket parts.

2.4.4 WARRANTY RETURNS

Warranty returns are products that are returned by the end users within a limited period as specified by the product manufacturer or remanufacturers [18]. Products returned within the warranty period are failed units or products that were purchased and returned due to customer being unsatisfied with the product. Once the product fails within the warranty period, irrespective of the reason for the return, the products are treated as faulty by default. Most manufacturers, remanufacturers and retailers request the customer to submit or attach a returns material authorization (RMA) document which is normally authorized by the manufacturer or remanufacturer beforehand for recording details regarding the reasons for the failure or return of the product [19]. Nevertheless, it is seen that in practice, this procedure is sometimes not carried out due to the fact that the customer is expected to identify the issue and fill up the (RMA) document before sending the product back to the manufacturer/ remanufacturers. In most cases, the customer will not have the expertise to do so. There will also be the tendency to accept returned products 'no questions asked' in order to maintain good relationships with the customers. These are some of the real life challenges which could impact negatively on the remanufacturing process and have to be managed.

2.4.5 MARKET ACCEPTANCE

Just as market forces cannot be ignored when introducing a new product, they must also be taken into account when introducing remanufactured products. Because customer perceptions are particularly important with the latter, market reaction may be more difficult to access for a remanufactured product than for new products.

Uninformed, initial perceptions of products containing used components are generally negative. For many products, this is a serious impediment to developing a viable market. Other potential customers may be concerned about the longevity of the remanufactured product, the cost of maintenance, and the product's durability. These concerns are once again some of the challenges which must be addressed before any market penetration can occur. They have the potential of affecting the prices the remanufactured products will be able to command [20].

2.4.6 LOGISTICS AND AFTERSALES SUPPORT

Setting up the remanufacturing facility entails some amount of capital investment in terms of equipment for disassembly, assembly, testing, distribution logistics and warehousing for the finished goods to provide customer access. Due to warranties associated with remanufactured goods, they may require field maintenance supports as well as spare parts availability [15, 20].

Clearly this review shows that there are bound to be challenges that could be encountered with the process just as in any human endeavor. These can be managed but not eliminated. On the other hand, there are huge potentials in remanufacturing in Ghana and Africa as a whole, potentials in terms of the benefits outlined earlier which in reality far outweighs the challenges. It is an avenue for skills development, employment generation and wealth creation. It is a way of conserving the environment, and also increasing the confidence and satisfaction levels of consumers of used products. This Project is therefore a useful guide to individuals, organizations or corporate institution who might be interested in tapping into the huge potential it brings.

CHAPTER THREE

CLASSIFICATION OF USED MACHINERY AND PARTS IMPORTS INTO GHANA

Ghana, like any other developing Country engages in the importation of large volume of used machine parts and equipment into the Country. This may be due to the fact that manufacturing of these units are usually not done locally and new replacement parts are generally not readily available, or are expensive beyond the reach of the average person. These used parts are classified by the weight of their imports as well as their cost and taxes paid to government on their importation. This is to estimate the quantities of cores that may be available for remanufacturing.

3.1 CLASSIFICATION OF USED PARTS IMPORTS BY WEIGHT

Referring to table 3.1, a net mass of 87,401 metric tons of used parts was imported into the Country from 2005 to 2010. Referring to table 3.2, these range from parts and accessories of bodies including cabs, gear boxes, drive axles and differentials, safety seat belts, suspension shock absorbers, radiators, silencers, exhaust pipes, steering wheels to steering columns. Also from figure 3.1, approximately eighteen million tons of parts and accessories of bodies were imported into the Country from 2005 to 2010. These used parts usually came in whole units, for example engines, transmissions and final drives and were sold directly to customers and no major repair work carried on them. From table 3.2, an average of 48,194 units of engines is imported into the Country every year. This quantum of parts imports are clear indications of the availability of cores for remanufacturing in the Country.

TABLE 3.1: Summary of Parts Imports From 2005-2010

Summary of Vehicle Parts Imports- Weight of Imports, Import Duty, Cost, Insurance & Freight (CIF) & Other Taxes Paid; 2005-2010				
Year	Net Mass/kg	CIF (GHc)	Import Duty (GHc)	Other Taxes (GHc)
2005	12,083,990.00	19,949,880.48	4,263,677.84	2,689,621.40
2006	10,473,962.86	22,456,416.51	4,812,776.67	2,984,274.67
2007	19,128,111.00	40,501,885.04	6,621,627.29	6,621,627.29
2008	13,779,895.00	46,535,002.35	9,464,548.79	9,464,548.79
2009	15,240,652.00	72,684,005.05	11,485,105.65	7,177,816.94
2010	16,694,366.00	65,540,345.20	13,605,182.08	1,884,719.97
TOTAL	**87,400,976.86**	**267,667,534.63**	**50,252,918.32**	**30,822,609.06**

Source: Customs Division of GRA (3/7/2011)

TABLE 3.2: Legend for Figures 3. 1, 3.2 & 3.3

NO	COMPONENT DESCRIPTION
1	Bumpers and parts thereof
2	Safety seat belts
3	Parts and accessories of bodies (incl. cabs)
4	Gear boxes
5	Drive-axles with differential
6	Road wheels and parts and accessories thereof
7	Suspension shock absorbers
8	Radiators
9	Silencers and exhaust pipes
10	Clutches and parts thereof
11	Steering wheels, steering columns and steering boxes
12	Parts and accessories, for vehicles
13	Brakes and servo-brakes and their parts (excl. mounted brake linings)
14	Mounted brake linings
15	Non-driving axles and their parts
16	Parts of works trucks
17	Parts of trailers and semi-trailers
18	Other miscellaneous parts

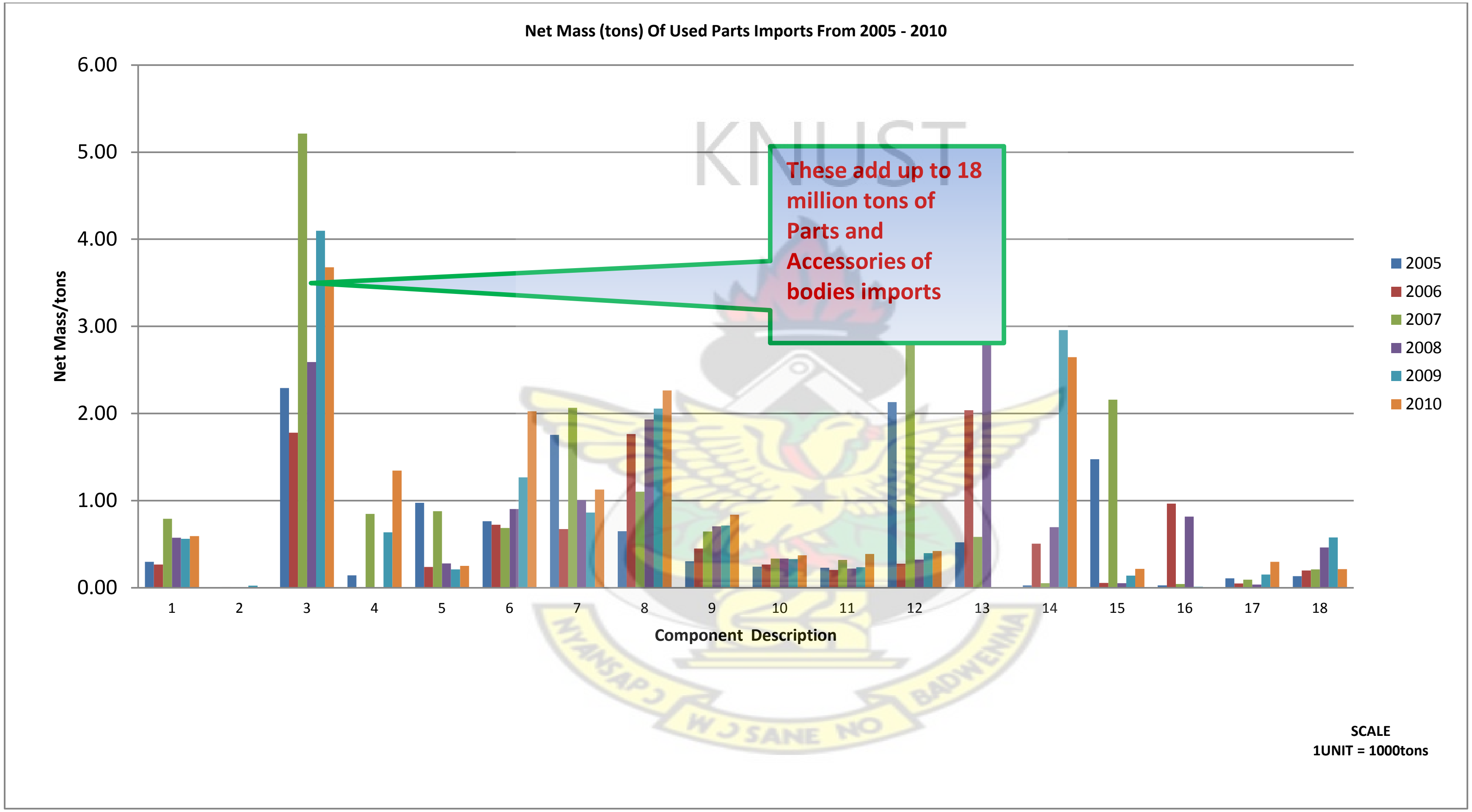

Figure 3.1: Net mass (tons) of imported used parts from 2005 – 2010

3.2 CLASSIFICATION OF USED PARTS IMPORTS BY COST

Cost, insurance and freight (CIF) on the used parts imports deduced from Table 3.1 from 2005-2010 was GHc 267,667,534.63. With such cost, no government may master the political will to ban the importation of these parts for reasons of the environmental and other problems outlined earlier in the review. The challenge now is how to put the parts into beneficial uses through the process of remanufacturing. These cost amounts are also indications of massive investment by entrepreneurs in these areas. Figure 3.2 shows the trend of cost of these importations over six years period (2005-2010).Mounted brake linings and parts and accessories of bodies including cabs according to Fig 3.2, show quite significant figures in terms of cost of the imports with figures of GHc 59, 005,468.10 and GHc 50, 527,147.47 respectively. Brake linings and some of the parts and accessories of bodies can be remanufactured. The seemingly high trend of imports of spare parts can be attributed to the demand for such replacement parts in the system.

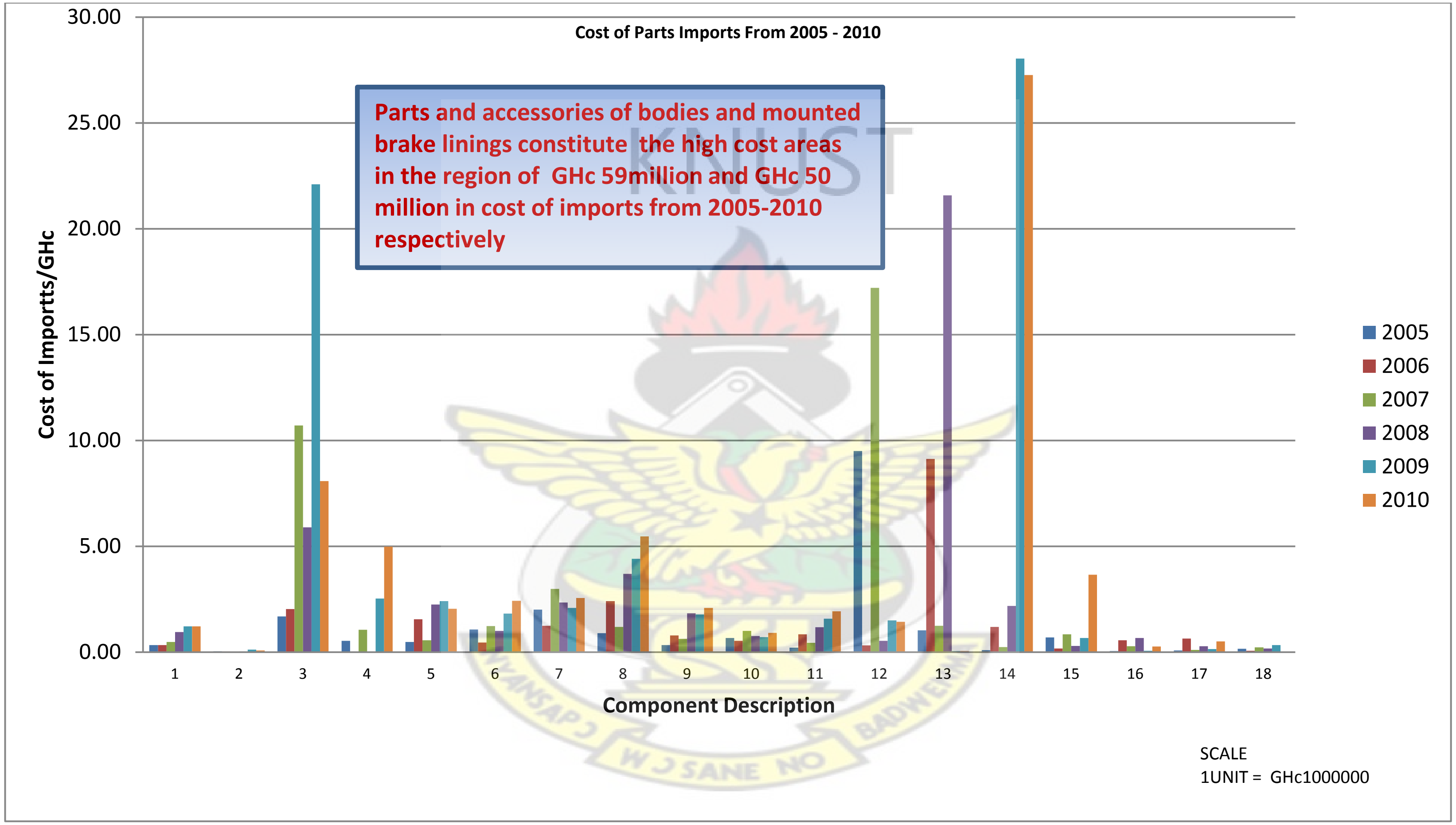

Figure 3.2: Cost of part imports from 2005 to 2010

3.3 CLASSIFICATION OF IMPORTS BY TAXES PAID

From figure 3.3, over GH₵19 million was realized by government on taxes paid on the import of mounted brake linings and servo brake parts from the period 2005 to 2010. Data from Table 3.1 also indicates that a total of GH₵50, 252,919.32 was realized by government as taxes from import duties, VAT/NHIL, Processing, ECOWAS and EDIF Levies on used parts excluding engines from 2005 to 2010. The high taxes generated from these imports could hinder any efforts to reduce the imports and this is an indication that these cores will always be available in the system and possibly increase in numbers.

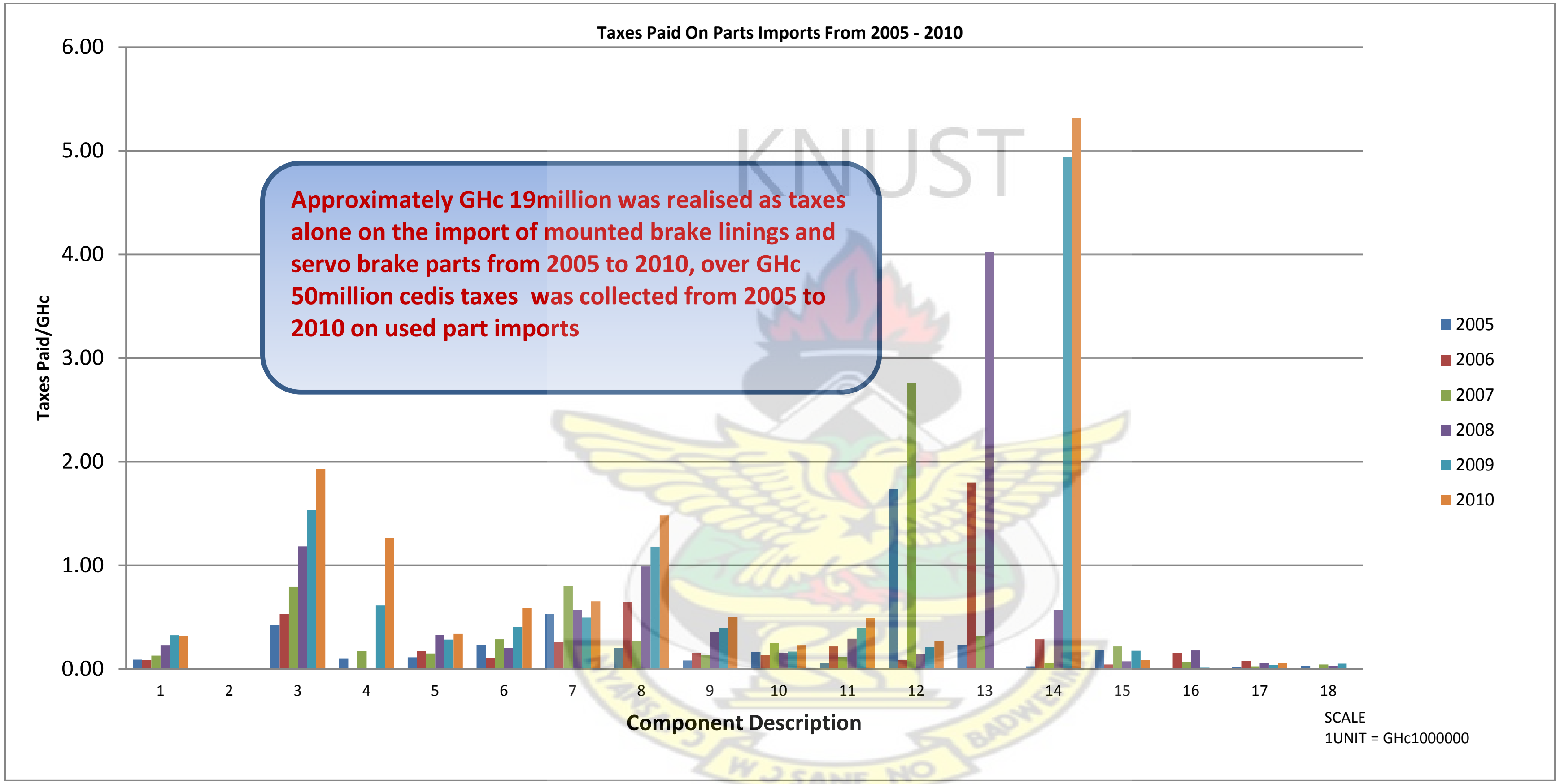

Figure 3.3: Taxes paid on parts imports from 2005 – 2010

3.4 IMPORTATION OF ENGINES WITH OR WITHOUT GEAR BOXES

From table 3.3, a total of 144,583 units of vehicle engines have been imported into the Country between the periods 2008 to 2010 with about 30% coming in from South Korea. This gives an average of forty eight thousand one hundred and ninety four (48,194) units of imports per year. Engines which come in whole units and can be purchased and used immediately on a machine could be remanufactured, just like a gear box or final drive. These could be specific target areas for remanufacturing. The above details are illustrated by figures 3.4 and 3.5 below respectively.

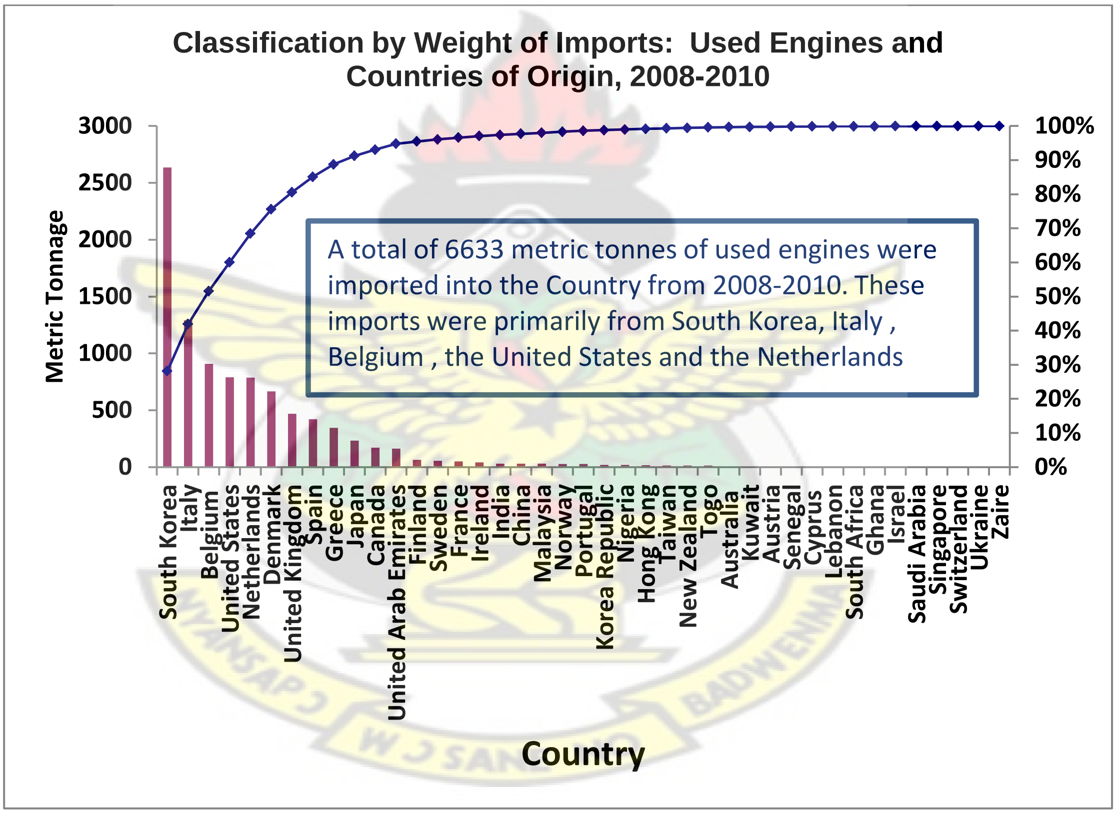

Figure 3.4: Classification by Weight of Imports: Used Engines and Countries of Origin: 2008-2010

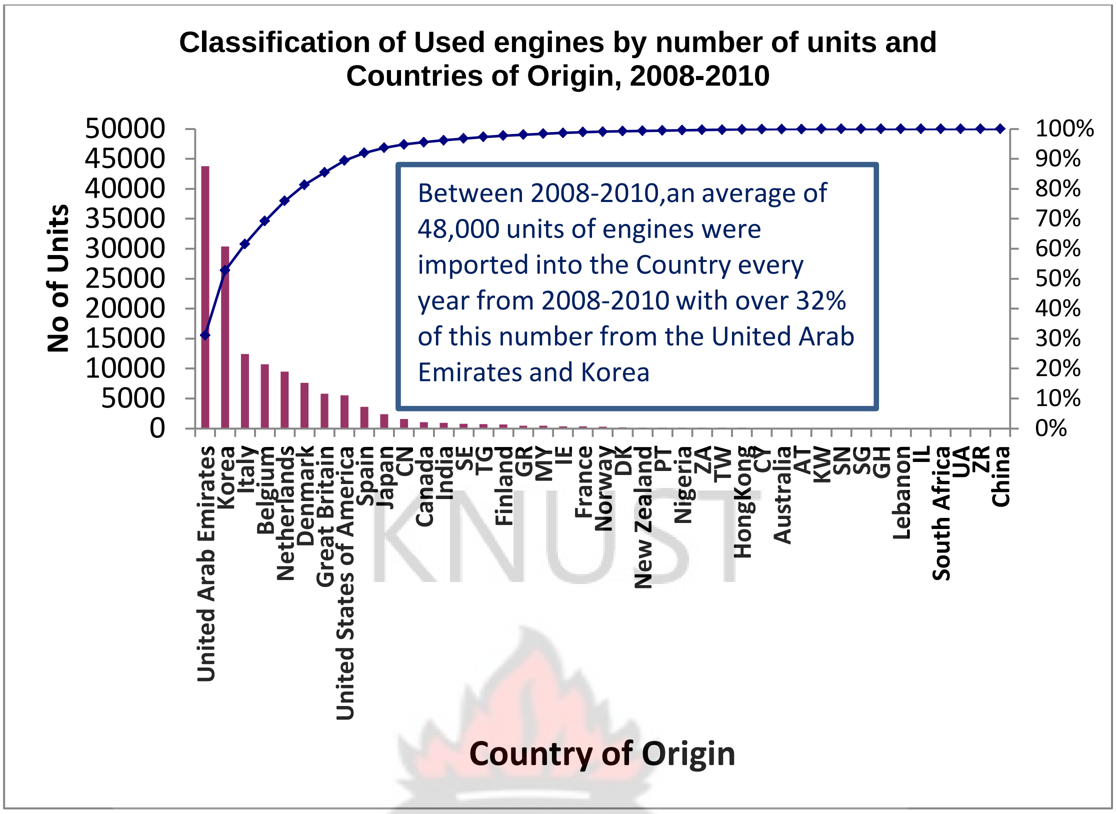

Figure 3.5: Classification of Used engines by number of units and Countries of Origin, 2008-2010

TABLE 3.3: Summary of Engine with or without Gear Box Imports from 2008-2010

Year	Number of Units of Engines Imported
2008	39,936
2009	39,036
2010	65,611
Total	**144,583.**

Source: Customs Division of GRA (3/7/2011)

CHAPTER FOUR

REMANUFACTURING: A CASE OF ENGINE REMANUFACTURE

The process of remanufacturing is illustrated with a detailed explanation of the remanufacture of an engine from strip down to inspection, re-assembly and testing. With the identification of the core, the process involves the following stages: Initial Cleaning /Disassembly, Inspection, Reconditioning or Replacement of Worn Parts, Re-assembly and Quality assurance testing.

In remanufacturing, the best industry practice is employed for each of the processes outlined above to qualify it for a warranty certification and this is what this project seeks to do. These processes are explained in the following sections.

4.1 INITIAL CLEANING/DISASSEMBLY

Having identified the core of the product to be remanufactured, the first major step after initial cleaning is the disassembly of the core for assessment. Preliminary high pressure washing is carried out to clean the core. For this process, a high pressure water spray nozzle is normally a requirement but not an extreme necessity. The high pressure washing helps in cleaning mud that normally gets stuck on the core. Disassembly is normally carried out in an orderly manner for easy identification and assessment of the parts and re-assembly. Tooling required for the disassembly are basic workshop tools, other special tools may be required depending on the type of product being handled. This process is a general one for all processes and is not limited to engine remanufacture alone. Not much skill and expertise is required for this process.

4.2 INSPECTION, RE-CONDITIONING OR REPLACEMENT OF WORN PARTS

The next step after the disassembly is cleaning and inspection of the parts for failure and signs or symptoms of failure. This process requires the use of failure criteria data from the original equipment manufacturer. However, a good experience in the judgment for re-use can be a good substitute for dependence on manufacturer's specifications. A good experience in failure analysis could also be an added advantage. For the case of an engine, components that are to be inspected for re-use, reconditioning or replacement are listed as follows:

- CYLINDER BLOCK
- CYLINDER HEAD
- CRANKSHAFT
- CYLINDER LINERS
- PISTONS AND PISTON RINGS
- MAIN AND CONNECTING ROD BEARINGS
- VALVE AND VALVE SEATS
- OVERHAULING GASKET KITS
- ELECTRICAL PARTS
- TIMING SYSTEM
- OIL PUMP
- WATER PUMP
- INJECTION PUMP AND INJECTORS

These represent the major and standard components of an engine. Some more additions may be included depending on the design of the type of engine being handled. Some additions may include turbochargers and aftercoolers.

4.2.1 CYLINDER BLOCK

Cylinder blocks constitute one of the most expensive parts of an engine. A situation under which a cylinder block cannot be re-used is where there is evidence of main or crankpin bearing failure during which a possibility exist for the main journals to seize. In such situations, there will be the possibility of the crankshaft not being able to turn and line boring can be done as an alternative process to salvage the block. The crankshaft cannot be re-used if line boring cannot salvage it. A possible evidence of internal crack is when all possible causes of oil or water dilution have been eliminated and a dilution problem still exists. This is where a replacement of the engine block with a new one is recommended. When such situations arise, that particular engine cannot be remanufactured unless the block is replaced which might render the remanufacturing cost more expensive. Hence the block is a major component which should be readily available for re-use in remanufacturing.

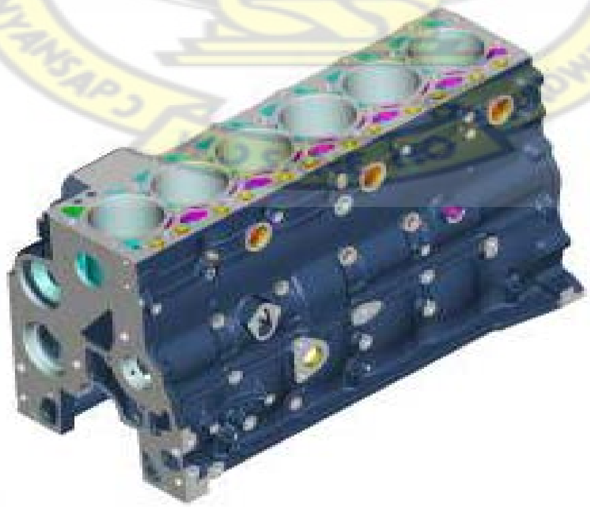

Figure 4.1: A six cylinder block for Remanufacturing

4.2.2 CYLINDER HEAD

Cylinder heads are classified according to the engine's combustion system or shape of the cylinder head. A cylinder head can be the direct injection or pre-combustion system type. It can also be 2-valve, 4 valves depending on the type of engine.

The separated direct injection type is commonly used in large size engines while the single block heads are employed in small to medium size engines. The various types are illustrated in Fig 4.2

Figure 4.2: Direct injection separated and the single block pre-combustion type cylinder Head.

Source: Panafrican Mining Services, 2009

Cylinder heads function to retain the combustion pressure and also transfers and dissipates the generated heat from the combustion chamber. For performing these functions, the cylinder head must have adequate strength and durability to withstand the high pressures and temperatures. Cylinder head failures result from cracks due to improper combustion usually due to over fueling, incorrect injection timing as well as inadequate cooling or use of unsuitable coolant.

These will cause overheating of the combustion chamber of the cylinder head and as a result induce the development of cracks. Most of the cracks normally develop around the valve port and injector bore which is an area most exposed to excessive heat. Secondary failures also occur when foreign matter enter through the air intake and cause damage to the valve and valve seat, broken parts of which are hit by the piston head and bottom surface of the cylinder head. For the purposes of remanufacturing, a cylinder head can be re-used only after testing and confirmation of absence of cracks. Cylinder head testing for cracks is mandatory before the head will be re-used in remanufacturing. There are various methods deployed in the testing of cylinder heads, some of them are hydraulic pressure testing, spot checks and magnetic Particle Index Test.

Hydraulic Pressure Testing: During this test, all coolant passages are blocked off and air is injected at a pressure of between 40 to 60 psi (pounds per square inch) into the water jacket. The cylinder head is then submerged in water. Any air bubbles seen coming out of the water is an indication of internal crack in the cylinder head, which could necessitate a replacement.

Spot Check Test: Also known as the penetrant dye method, the cylinder head is cleaned of all carbon and a dye is applied to the surface and made to stay for at least five minutes as seen in figure 4.3

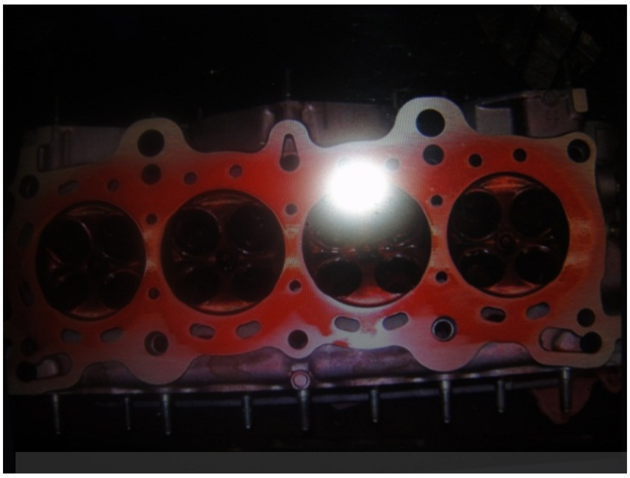

Figure 4.3: Cylinder head test showing bright red lines to aid in crack detection

A penetrant is then sprayed onto the head and after fifteen to twenty minutes, a developer which is also a chemical reagent is then sprayed onto the head and any crack on the head will show up as bright red lines. The testing tool for this method usually comes in the form of kits, an example of the kit is shown in fig 4.4

Figure 4.4: Penetrant Dye method kit for crack detection.

Magnetic Particle Index Test: With the kit for this test is illustrated by fig.4.5, this is also known as magna fluxing. It is a non-destructive testing (NDT) method. For this testing, a magnet is attached to the cylinder head and metal particles are sprayed onto it to reveal any internal cracks. When there is movement of the metal particles in any particular direction, it shows the presence of a crack in that direction. This method is mostly used for cast iron heads. For the purposes of remanufacturing, it is a mandatory routine for cylinder heads to be tested and certified to be free from cracks. This is an extremely important requirement as warranty failures from cracked cylinder heads come with enormous cost because of the cost of the part itself. Table 4.1 summarizes some of the failure criteria used in the assessment of crankshafts. Apart from the details explained above, table 4.1 gives a summary of other inspection points which are considered during the assessment of the parts for reuse.

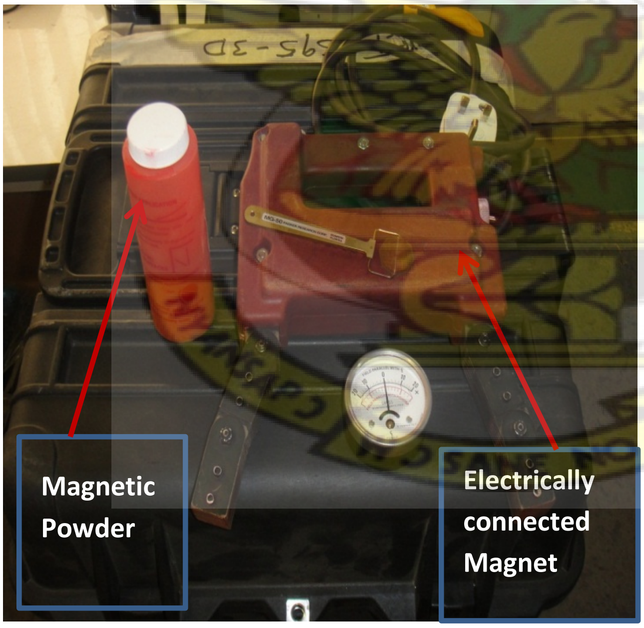

Figure 4.5: Magnetic Particle Index test kit.

TABLE 4.1: Summary of Determination of Failure of Cylinder Heads

FAILURE	FAILURE DEGREE	RANK.
Damage to Cylinder Head.	Visible cracks in the Intake & Exhaust valve port areas, usually visible after crack test	Replace.
Damage Cylinder Head.	Dents 0.5mm or less	Replace.
Fillet portion	Slight scratches and corrosion on bottom surface of head, but no crack	Corrosion observed is normally caused by combustion gases, due to foreign matter entering with intake air. Head can be re-used after re-conditioning by removing burrs with emery cloth.

4.2.3 CRANKSHAFT

After thoroughly cleaning the crankshaft, inspection is carried out with critical examination of the crankpin journal, main journal and fillet radius indicated below.

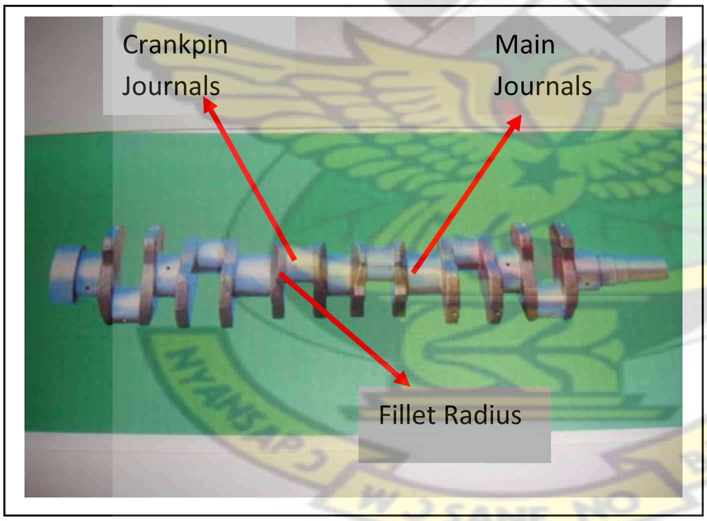

Figure 4.6: Crankshaft indicating specific inspection points for re-usage

Inspection of the main and crankpin journals are physically conducted for evidence of scratches, wear or discoloration. Depending on the extent of wear or failure, the crankshaft can be re-used again after re-conditioning. For the purposes of remanufacturing, re-conditioning is carried out by grinding using emery cloth. Other methods using specialized equipment for example a mechanically driven grinder may be used in which case an oversize bearing will be used. However, this method is not recommended as the risk associated with its use is quite high. Some of these risks could be using standard bearings for an undersized crankshaft, specifically; using the wrong choice of bearings for a machined crankshaft, improper machining which could lead to the introduction of stress raisers at fillets portions and many more. The best practice is to use standard bearings for a standard crankshaft which has been re-conditioned by polishing with emery cloth. Getting it wrong at this stage may cause low oil pressure and possibly failure which could be costly in terms of warranty replacement. Table 4.2 shows some of the standard criteria used in assessing crankshafts for re-use.

TABLE 4.2: Summary of Determination For Re-Use Of Crankshafts

FAILURE	FAILURE DEGREE	RANK
Damage to journal	Scratches or wear not felt by finger-nail	Use again after re-conditioning.
Damage to journal	Scratches felt by finger-nail	Use again after re-conditioning.
Fillet portion	No crack	Use again
Fillet Portion	Discernable circumferential Crack	Do not use again.
Grooved wear in contact surface with seal.	Discernable grooved wear, but not felt by finger-nail	Use again.
Grooved wear in contact surface with seal	Discernable and scratchable grooved wear, felt by finger-nail.	Use again after re-conditioning. Re-conditioning methods for such a condition range from shifting contact portion between crankshaft and seal lip by driving the seal, or inserting a sleeve.
Discolor in Journal	Discernable temper color and damage through melting.	Do not use again.
	No discolor	Use again after re-conditioning.
Hairy scratches felt by fingernail	Normally caused by incorrect oil maintenance, or dust and foreign matter entering.	Can be used again after re-conditioning.

It is also important to ensure that the main and crankpin journal diameters are within the tolerance limits of the original equipment manufacturer (OEM) by measuring and comparing to the OEM standards after the re-conditioning process is completed.

This is the final stage of the recommendation for re-use and requires some level of knowledge in the use of micrometer screw gauge or vernier caliper. A crankshaft can seize due to lack of lubricating oil, deterioration or decrease in the oil viscosity, due to poor oil maintenance or use of poor quality or improper oil and incorrect maintenance of oil filter. Replacing a damaged crankshaft during remanufacture may render the cost of the finished product more expensive and this is why remanufacturing is recommended for a moving or re-useable core. A re-useable core suggests that there is no seizure of the crankshaft to warrant its replacement during remanufacture.

4.2.4 CYLINDER LINERS

There are two types of cylinder liners, the wet type and the dry type. The wet type has seals separating the water jacket from the combustion chamber and is normally used for heavy duty engines whereas the dry type has not. Both the wet and dry types can be replaced by pressing. The external surface of the wet type cylinder liner is directly cooled by the cooling water; the top part is sealed off by the cylinder liner's flanged surface while the lower part is sealed by the liner's sealing rings as illustrated in figure 4.7,

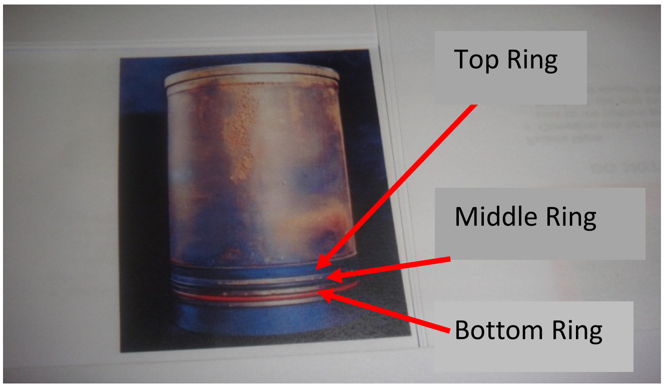

Figure 4.7: Wet type liner with the various types of seals

The top ring, also known as crevice seal has high resistance to heat, water and vibration. The middle ring, has high resistance to heat and water and the bottom ring, has high resistance to oil. Cylinder liner forms part of the combustion chamber, completed by the piston top and cylinder head. It performs the following functions;

a. Withstand the extremely high combustion pressure.

b. Be able to conduct the heat of combustion away from the chamber.

Cylinder liner failures result from cavitation. With this kind of failure, part of the cooling water surrounding the cylinder liner receives vibrations from the latter, first at the low pressure phase of a vibration, the saturated vapor in the water forms bubbles and at the high pressure phase of the vibration, the bubbles collapse. With their collapse, water rushes in to fill the void and this generates a shock wave that erodes the metal surface. The symptoms appear as tiny pits on the cylinder liners outside wall surface that is in contact with the cooling water. These pits grow in size and depth till they penetrate the cylinder liner wall and induce the growing of cracks in the cylinder liner. The cylinder liner wall side that receives the piston's thrust force and the opposite sides are most susceptible to cavitation erosion which is concentrated more on the upper and lower parts of the cylinder. Some of the causes of cavitation are as follows;

1. Abnormal and excessive vibration of the cylinder liner,
2. Mixing of air (aeration) in the cooling water because of insufficient filling,
3. Use of unsuitable cooling water,
4. Dirt or foreign matter in the cooling water.

Other possible causes of liner failure are overheating, over fuelling or entry of foreign matter. Poor or insufficient coolant can also result in deterioration of the liner seals. Liners are usually replaced almost all the time during remanufacturing with new ones. It is cheaper and an adherence to best practice if it is replaced during remanufacture.

4.2.5 PISTONS AND PISTON RINGS

Pistons are in direct contact with the combustion gases and expand with the heat produced, but contracts when it is cooled by the engine oil, through the piston rings. When running, the piston continuously expands and contracts, as such if the clearance between the piston and the cylinder liner is too large or too small, the oil film will be destroyed and the piston will make metal to metal contact with the cylinder liner, thereby producing seizure and scuffing. This clearance is always required to be within specified tolerances. When the engine is running, the top surface of the piston is subjected to the high heat of combustion gases, and tends to expand; however the piston periphery which is being cooled resists the expansion and causes stresses to develop in the heated area. In situations of severe overheating when these stresses exceed the material yield point, plastic deformation will occur and metal fatigue from heating and high temperature usually referred to as thermal fatigue will cause cracks to develop.

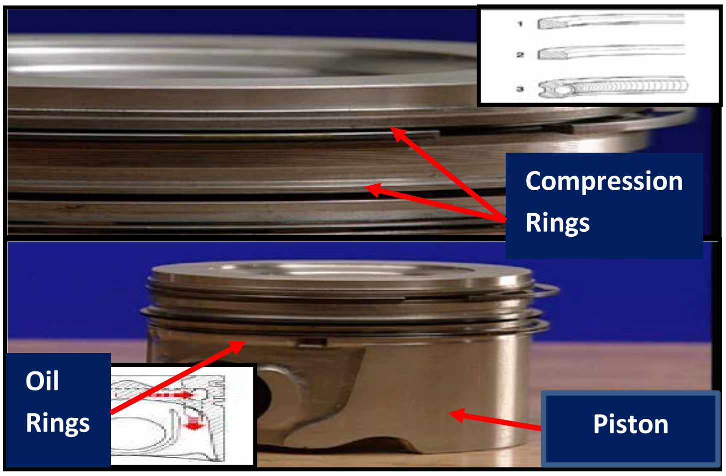

Figure 4.8: Positioning of the oil and compression rings

These symptoms can also occur due to poor spraying of the injected fuel, over fueling or localized overheating caused by mistiming of the fuel injection. For these reasons; it is recommended during remanufacturing that pistons be replaced with new ones to avoid re-using pistons that have undergone plastic deformation. Similarly, piston rings must also be replaced with new ones during remanufacture. This is because the compression rings installed on the piston keeps the combustion chamber gas tight, while the oil ring returns the engine oil spent in the lubrication and cooling of the piston to the engine oil sump, and prevents oil from seeping up into the combustion chamber. For the purposes of remanufacturing, such functions cannot be compromised with the use of used piston rings and hence has to be replaced with new ones except in exceptional cases where compelling evidence has been established to justify its re-use.

4.2.6 MAIN AND CONNECTING ROD BEARINGS

Main and connecting rod bearings consist of the main journal bearings usually built in the cylinder block and the connecting rod bearings. Each of these is assembled as upper and lower half of round split and arranged with oil grooves of two or three layers so as to make the best use of the characteristics of the material of the bearing. Failure of these bearings usually results from corrosion as a result of improper lubrication resulting from use of poor quality oil or deteriorated oil. Cavitation due to presence of water or anti-freeze in the lubricant can also lead to flaking failure.

Flaking failure results from partial overload due to eccentric loading. This is as a result of bend in crankshaft or connecting rod, and abnormal combustion in engine.

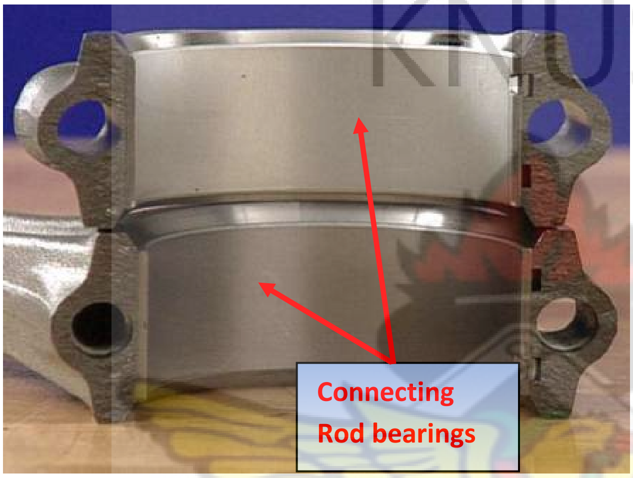

Figure 4.9: Connecting rod fitted with connecting rod bearings

Connecting rod bearings usually undergo either abrasive or adhesive wear during the service life of the engine and they are most often replaced with new ones during remanufacturing of an engine. Abrasive wear may occur due to contamination of the engine oil when foreign particles get into the oil and adhesive wear, which is wear resulting from metal to metal contact occurs when there is a lack of lubricating oil. The other underlying reason why they should be replaced is that warranty failures from connecting rods could also be very expensive because it is an internal part.

4.2.7 CONNECTING RODS

Connecting rods are in most cases re-used during remanufacture. It connects the piston to the crankshaft and converts linear motion of the piston to rotating motion of the crankshaft. Conditions under which connecting rods can be replaced are situations when side clearances far exceed manufacturer's specifications for that engine. The side clearance is measured with a dial gauge. The side clearance is measured with the connecting rod on the crankshaft in the course of stripping the engine.

Individual clearances are measured and recorded and afterwards compared to recommended clearances. Due to the high speed of rotation of connecting rods, when measured side clearances exceed recommended specifications, that particular rod will have to be replaced with a new one.

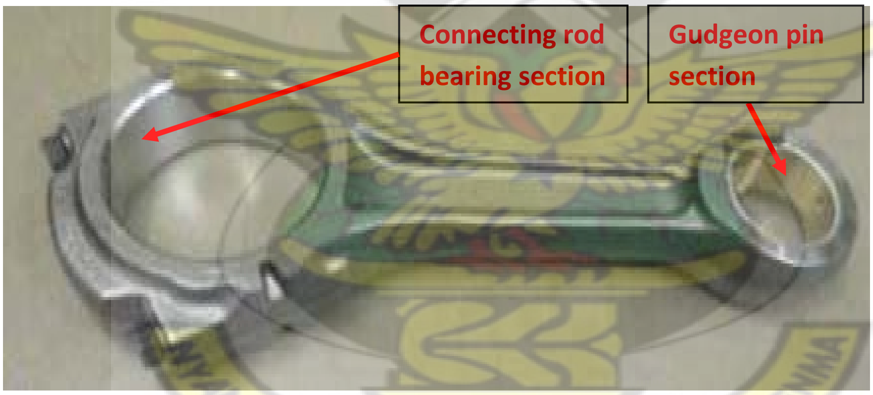

Figure 4.10: Connecting rod with the bearing and gudgeon pin sections

4.2.8 VALVE AND VALVE SEATS

Common damage to valves and valve seats which is usually the melting of the valve face may result from rapid and excessive heating caused by over fueling or improper injection timing. Also cracks or abnormal wear may result from foreign matter passed through the air intake, or carbon deposits becoming jammed between the valve and its seat. There could also be abnormal wear and seizing resulting from mixing of dirt, water and fuel in the engine oil, causing lowering of its viscosity and lubricating properties which in turn cause metal to metal contact leading to failure. The various components of the valves are illustrated in figure 5.0

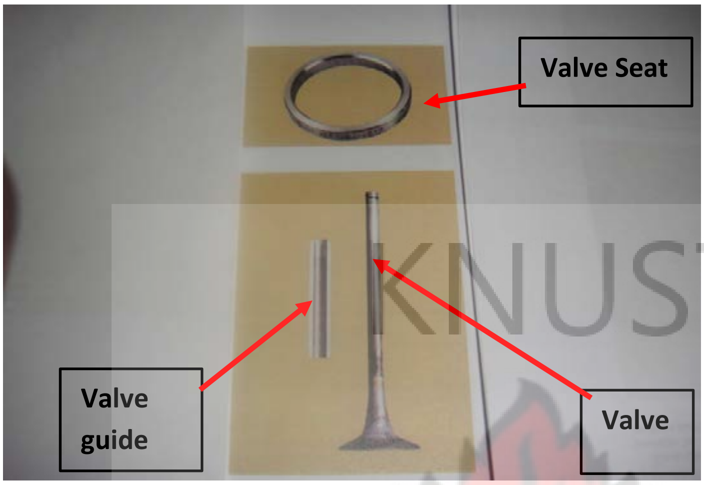

Figure 4.11: Cylinder valves with seat and guide

These failures may be caused by insufficient engine oil, water and fuel leakage, or foreign matter mixed with the intake air. Intake and exhaust valves, valve seats and guides are usually replaced with new ones during remanufacturing unless sufficiently high evidence exists to suggest that it can be re-used. The best industry practice especially with remanufacturing is to replace them with new ones.

4.2.9 OVERHAULING GASKET KITS

Overhauling gasket kits contain the various seals and O-rings for the remanufacturing process of an engine. They normally come as two parts, the head kit and the block kit. For the purposes of remanufacturing these kits are to be obtained from the original equipment manufacturer to avoid the use of faked or substandard seals and O-rings. The use of fake, substandard or after-market kits for the remanufacturing process could possibly lead to pre-mature failure and heavy warranty costs.

4.2.10 ELECTRICAL PARTS

Warranty on remanufactured units does not usually cover electrical parts like starters and alternators. It is however recommended that these parts are tested and confirmed to be functional and repaired when necessary before being re-used. Under uncertain conditions about the performance, it should be replaced with new ones preferably from the original equipment manufacturer.

4.2.11 TIMING GEARS

Timing gears as indicated in figure 4.10 are usually re-used during re-manufacture. They are only replaced when the backlash is high and exceeds manufacturer's specifications or when there is breakage or severe wear. However bushings, bearings and thrust washers on them are usually replaced with new ones on remanufacture. Other engines use timing chains, or timing belts. These ones are to be replaced with new ones during remanufacture. Figures 4.12 and 4.13 show the nature of the timing gears of heavy duty engines and timing chains of light duty vehicles. During remanufacture, it is important to ensure that these gears or chains are correctly aligned to the markers on them to avoid any possible cases of mistiming. When there is mistiming, the engine when cranked will not start and the consequences could possibly be an expensive damage.

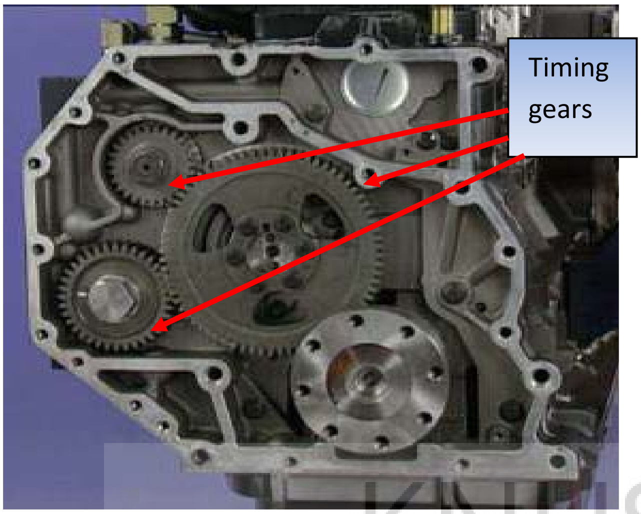

Figure 4.12: Timing gears of a heavy duty engine

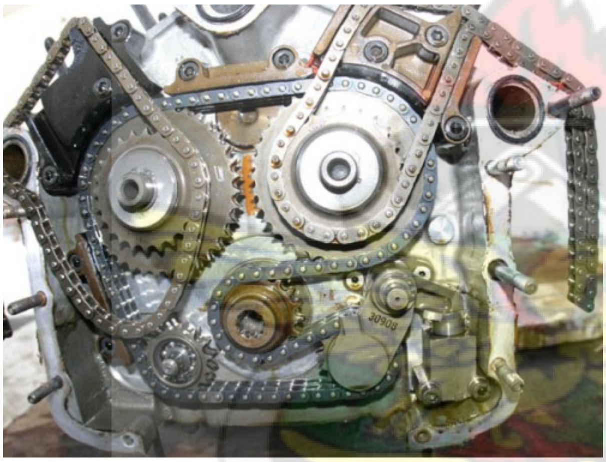

Figure 4.13: Timing Chains of a light duty vehicle

4.2.12 OIL PUMP

The oil pump is an important part of the engine. Failure of the oil pump to properly lubricate the engine can result in engine failure. Oil pumps are usually fixed displacement gear pumps and oil pump pressure is required to be within specified limits at all times in the life of the engine to ensure adequate lubrication. Oil pumps can be re-used depending on the physical condition of the mating gears and the running hours of the engine. Re-conditioning is not usually recommended, replacement with a new one is the best option. This is because it is an internal part and its replacement on the field when the equipment is working is usually not possible. A failure of an oil pump most frequently result in lack of proper lubrication and consequently engine failure. It is therefore a mandatory replacement part during remanufacture.

4.2.13 WATER PUMP

Water pumps also play a vital role in the life of the engine. Working alongside thermostats, water pumps function to ensure that engine coolant temperature levels are within the specified range. This range is between 60-80 degrees Celsius which is the desired working temperature for most engines. Depending on the condition, water pumps can be re-conditioned and re-used. Figure 4.14 is an example of a water pump of a light duty engine.

Figure 4.14: Water Pump for a light duty engine

Re-conditioning for remanufacture requires a mandatory replacement of the impeller and shaft with a new one. This is to ensure that interference fit between the impeller and the shaft is always maintained to avoid the impeller turning on the shaft or vice versa. When this requirement is not met or maintained, it can cause improper circulation of the coolant which may result in overheating. Water pumps can therefore be re-conditioned and re-used depending on the state.

4.2.14 CROSS HEADS

Cross heads are usually re-conditioned and re-used. Due to valve adjustments associated with cross heads, polishing is done well to ensure that valve clearances are accurately obtained. Fig 4.15 shows the nature of crossheads on a heavy duty engine. There are other designs depending on the make of the engine.

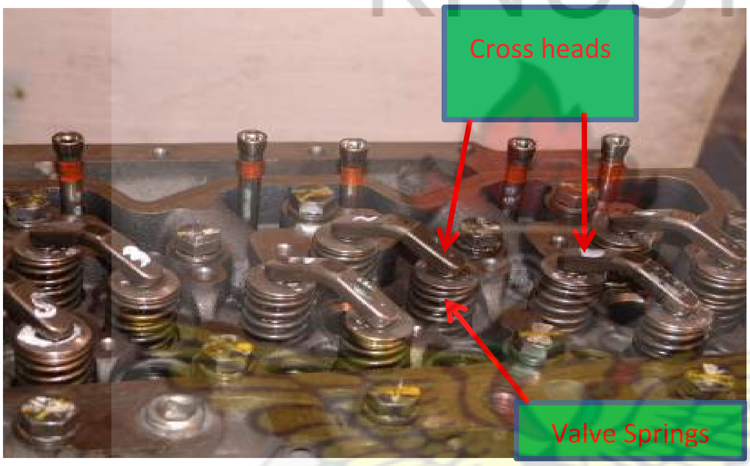

Figure 4.15: Cross Heads with valve springs

Crossheads are usually re-conditioned by polishing and re-used unless there is excessive wear to warrant their replacement.

4.2.15 INJECTION PUMP AND INJECTORS

Injection pump and injectors remanufacture represents one of the most challenging aspects of remanufacturing. This is because, apart from them being seen as the heart of the engine, they also require a lot of skill and expertise in their remanufacture. Getting it right is necessary to ensure proper performance of the engine in terms of horsepower requirement, torque, fuel efficiency etc. The repair, overhaul or remanufacture of an injection pump requires a test bench which will be used to test and re-calibrate the pump after overhaul as well as a nozzle tester which will also be used to test and adjust nozzle opening pressures. The calibration data of that particular type of pump from the manufacturer is also needed to set fuel delivery and timing as well as revolutions per minute (rpm) at the required specifications. All the above listed requirements require a high level of training for the staff who may handle the process. There are two types of injection systems usually employed in modern engines. These are as follows;

a. Common Rail Injection Pump and Common Rail Injectors

Common Rail Injection pumps which are applicable to both diesel and petrol engines, can be overhauled and re-calibrated on a test bench with special tooling for the removal of the plungers, camshafts and tappets for assessment and re-conditioning or replacement. On the other hand an alternative is to replace the pump with a new one during remanufacture which is currently what is prevailing in the few companies in the country where remanufacturing is carried out because of the skill and investment needed to carry out the process. Figure 4.16 and 4.17 shows an example of common rail injectors and injection pump respectively for a diesel engine which are highly sensitive to dust. The components of the high pressure common rail injection system are as follows:

1. The fuel supply unit (Fuel tank).
2. The common rail injection pump usually called the supply pump (fig.4.17)
3. The common rail injector (fig.4.16), and

The Electronic Control Unit (ECU), which, depending on the torque requirement of the equipment/vehicle, sends electronic signals to the injectors which open in accordance with the demand, for the injector to spray fuel into the combustion chamber, regulating the flow and discharge.

Figure 4.16: Common Rail Injectors

Figure 4.17: Common Rail Injection Pump

b. <u>Mechanical Governor Injection Pumps</u>

Mechanical governor pumps have mechanical control for the governor of the pump unlike the common rail which is electronic controlled. Mechanical governor injection pumps are no longer in use because of the following;

The need to reduce nitrogen oxide emissions all over the world has necessitated the introduction of the high pressure common rail injection system. Nitrogen oxide emissions have negative impacts on the environment. These oxides of nitrogen forms from the emissions from cars, trucks and buses, power plants and off-road equipment. In addition to contributing to the formation of ground level ozone, nitrogen oxide has been proven to have a number of adverse effects on the respiratory system [25]. It is now becoming a worldwide regulation for all auto industries to stop the production of mechanical pumps and replace them with the high pressure common rail system to be able to conform to emission control regulations [26]. No modern day engine employs the use of mechanical governor pumps and this is only mentioned as a way of identifying the types of injection pumps for the purposes of this research. A common type of test bench for testing common rail injection pumps is shown in fig 4.18. This is possibly one of the highest cost investment areas for remanufacturing of engines in addition to a dynamometer.

Figure 4.18: Common rail injection pump test stand

4.3 RE-ASSEMBLY PROCESS

The next phase in the remanufacturing process after disassembly, cleaning and functional testing is the re-assembly process. At this stage, it is expected that re-useable parts have been re-conditioned to be re-used and damaged parts replaced with new ones from the original equipment manufacturer. Tools and materials required for re-assembly are as follows;

1. Torque wrenches: Torque wrenches are tools required to be used throughout the re-assembly process to ensure that all bolts are tightened to specifications. This is a mandatory requirement and guess tightening is not allowed. Various tightening torques for the various bolts can be obtained from the shop manual of the particular engine.

2. Dial gauge: A dial gauge is a tool that will be used in checking liner protrusion, timing gear backlash, connecting rod side clearance and crankshaft end-play. This is a standard and mandatory requirement in remanufacturing.

3. Unit repair stand: This is a device used to mount the engine and is capable of rotating the engine to any angle required.

4. Liner installer: A tool for the installation of the liners.

5. Piston Installer: A tool for the installation of the pistons.

6. Ring, flat and socket spanner set: These are standard and required tools and depending on the component being handled, they could be heavy duty or light duty tools.

7. Loctite: This is a material for use on internal bolts.

8. Sealant: A material for wet liners and can be used throughout the process when necessary.

Other tools not mentioned here may be considered necessary depending on the type of engine being assembled.

The re-assembly process requires a greater amount of skill and this is the stage where a lot of precision and on the job experience is required to ensure quality finished product. In most cases poor quality work will be manifested during dynamometer testing. A remanufactured engine has to pass a vigorous dynamometer test before it can be sold with warranty. The process of re-assembly is shown on the detailed process flow diagram in figure 4.19. The flow diagram has no decision points because at this stage, it is expected that all damaged parts have been replaced or re-conditioned and the necessary new parts and installation equipment and tools have been obtained. Standard tightening torques and procedures outlined in figure. 4.19 are used throughout the process. Some of the steps may vary depending on the design of the engine.

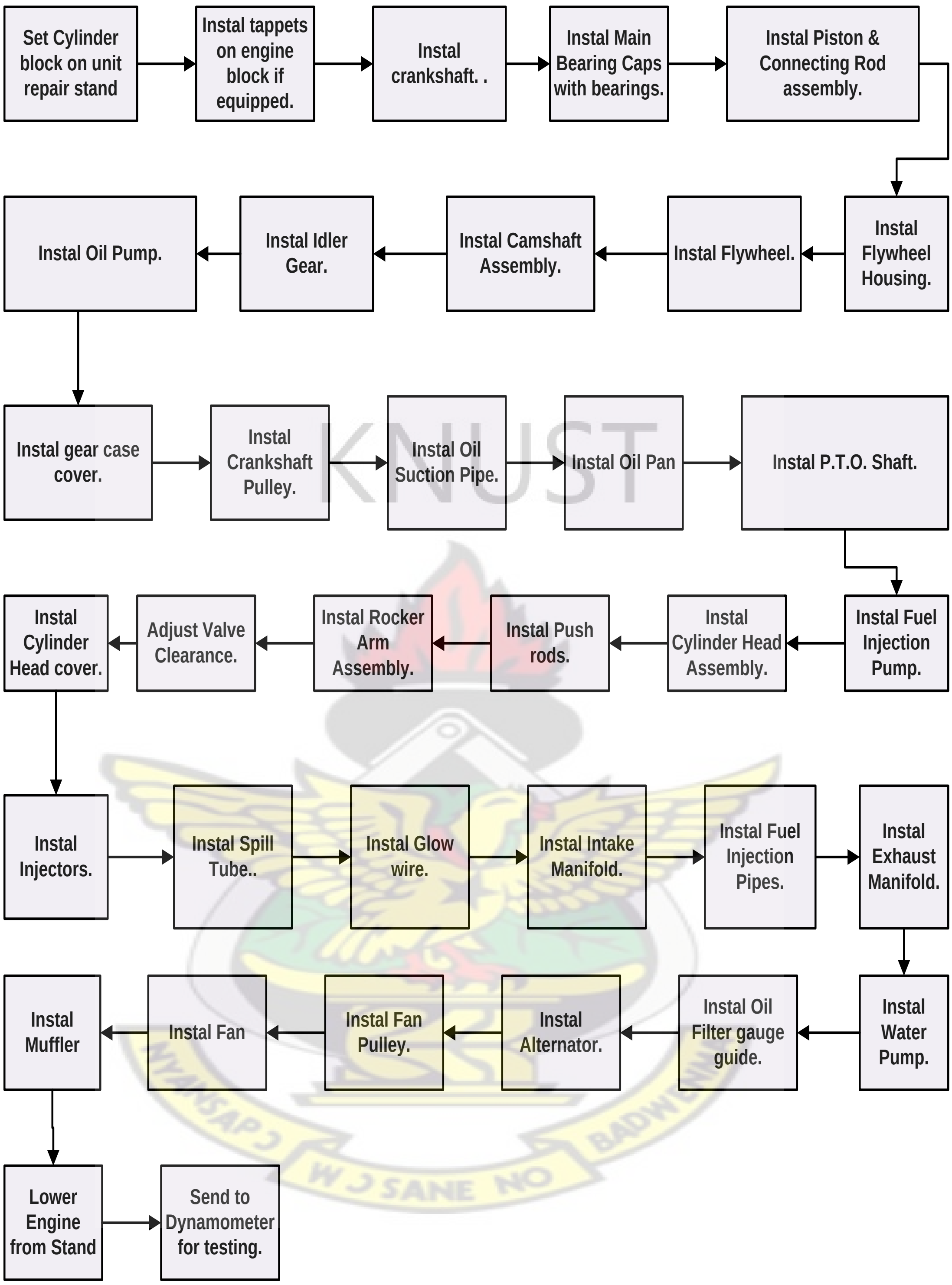

Figure 4.19: Sequence of steps for engine re-assembly

4.4 VALVE CLEARANCE ADJUSTMENT

This is a standard requirement for all engines and the procedure for the adjustment is as follows:

With the cylinder head cover removed and using the front of the engine as the reference point, the crankshaft is rotated in a clockwise direction while observing the movement of the intake valve of the last cylinder which could be the number four cylinder if it is a four cylinder engine, or the number six cylinder if it is a six cylinder engine. With the clockwise rotation, the number one cylinder is brought into compression top dead center position. A pointer on top of the damper of the crankshaft should align with the TOP1, 6 or TOP1, 4 positions indicated on the damper to confirm that the number one cylinder is in the compression stroke or compression top dead center position. When the number one cylinder comes near compression top dead center position, the number six cylinder (for a six cylinder engine), number four cylinder (for a four cylinder engine) will start to move (open). At this time, the valves are adjusted on the rocker arm as follows; for a six cylinder engine,

Number 1 intake and exhaust

Number 2 intake, number 3 exhaust

Number 4 intake and number 5 exhaust

Both intake and exhaust for number 6 is not adjusted

After this, the crankshaft is rotated in a clockwise direction for one complete revolution (360 degrees Celsius) and valve clearances are adjusted, this time, from the opposite direction in the same manner as the first adjustment procedure before.

The adjustment is done on the clearance between the valve stem and the rocker arm using a feeler gauge and the clearances are set as follows:

Intake valve: 0.35mm

Exhaust valve 0.50mm

This is for a six cylinder 140 mm bore diameter engine and is a necessary requirement to ensure correct opening clearances and closing of the valves during the combustion process. This process primarily ensures that correct air/fuel ratios are obtained to avoid incomplete combustion.

4.5 QUALITY ASSURANCE TESTING

Quality assurance testing represents one of the crucial stages in the remanufacturing process which determines product quality and conformity to (OEM) specifications. The requirement for this process is a dynamometer with capacity suitable for testing the engine in question. For an engine remanufacture, a satisfied properly documented dynamometer performance increases the level of confidence on any warranty to be given to the finished product. It is a primary distinguishing criteria between a remanufactured component and a repaired/rebuilt/overhauled one. Testing could take hours or days to complete depending on when the component under test is able to pass all the dynamometer performance requirements. The stages of dynamometer testing of an engine include run-in or warming up of the engine, increasing the revolutions per minute at various stages for thermostat opening temperatures to be obtained. This is normally at temperatures between 70-80 degrees Celsius before the engine is subjected to loads.

The objective of this process is to ensure proper seating of seals and observation of any abnormalities before subjecting the engine to heavy loading [21, 23, 24].

This test is conducted to correct and confirm the following: Internal and External Leakages, Flywheel Horsepower and Maximum Torque, Crankcase Pressure, Boost Pressure, Oil Pressure (at both low and high idling), Exhaust Color.

4.5.1 INTERNAL AND EXTERNAL LEAKAGES

Leakages on the engine internally and externally at thermostat opening temperatures can be observed by physical inspection of the engine body and by inspecting the lubricating oil and water for dilution. Generally, any dilution of either the oil or water could possibly be an indication of internal leakage [21, 23, 24]. Such leakages either external or internal may have to be corrected before the dynamometer test could be continued.

4.5.2 FLYWHEEL HORSEPOWER AND MAXIMUM TORQUE

Most heavy duty test dynamometers use water flow resistance to vary output loading to an engine coupled to it. The loading to the engine is increased by increasing the volume of water flow to the vanes of the dynamometer. This increases the loading to the engine and subsequently the torque and horsepower generated by the engine. It is then measured at various specified revolutions per minute (rpm) which are then compared to the OEM specifications. When these values obtained do not conform to the required specifications, adjustments are normally made on the governor of the fuel injection pump or on the electronic control unit (ECU). In most cases, the correct specifications are obtained only when the injection pump and the injectors have also been overhauled and correctly re-calibrated on a test bench as explained earlier [22, 24].

4.5.3 CRANKCASE PRESSURE

Crankcase pressure usually referred to as blow-by pressure indicates the escape of combustion gases into the crankcase. This is an indication of the quality of sealing of the piston rings. Blow-by pressures are normally measured in milliliters of water from the breather. A good blow-by measure (which usually varies depending on the specifications of the engine) is an indication of high durability of the engine [21]. As the engine works and the running hours increases, blow-by increases progressively and with good maintenance, this can be kept to the barest minimum at all times until the point when the rings get worn out to allow escape of gases into the combustion chamber.

4.5.4 BOOST PRESSURE

Boost pressure which is an indication of turbocharger performance and quality is usually measured on the turbocharger. Turbocharger performance can also be determined physically by checking the play of the main shaft of the turbine and blower. If excessive clearance exists (which also depends on the specifications of the engine), the core may have to be replaced with a new one. Replacing the turbocharger assembly is often quite expensive compared to replacement of the core alone which invariably leads to the same end result [22].

4.5.5 OIL PRESSURE AT LOW AND HIGH IDLING

Oil pressure intake port is at any point on the oil line on the engine block. Oil pressure is an indication of the quality of the oil pump and its ability to circulate pressurized oil in the system. Conformity of such values to (OEM) specifications is very crucial and critical. For this reason, most remanufactures recommend a replacement of the oil pump with a new one/ part since it is normally an internal part. Engine low and high idling speeds are usually measured with a tachometer.

Attaining the requisite speeds is a requirement to avoiding excessive fuel consumption and generating the requisite torque and horsepower as well as avoiding engine overrunning (a phenomenon where a possibility exist for pistons and valves to collide) [22, 24].

4.5.6 EXHAUST COLOUR

Exhaust color is usually determined by visual inspection or by use of a special probe. Exhaust color is an indication of whether there is complete or incomplete combustion, or whether there is oil leakage into the combustion chamber. It is also an indication of the proper or improper function of the injectors. Injectors on a diesel engine are expected to spray atomized fuel into the combustion chamber. When it is not performing this function properly, i.e. when it is dribbling, there is the tendency to generate black smoke because of the excessive injection of fuel into the chamber. Leakage of oil into the combustion chamber due to weak oil rings or weak valve seals can also generate blue smoke [20, 21, and 22].

In summarizing quality assurance tests, dynamometer testing which is a standard requirement for engine remanufacture is usually performed using specifications and tolerances of the original equipment remanufacturer. Without proper and documented dynamometer testing results, warranty certification cannot be done and certifying an engine that has not passed through these requirements poses a greater risk to the remanufacturer. Quality assurance testing is therefore a must for all remanufactured products to tell the story of what really happens in the internal part of the component to serve as a basis for warranty certification.

4.5.7 ESTIMATED COST OF A REMANUFACTURED ENGINE COMPARED TO A NEW ONE

A practical demonstration of the estimated cost of remanufacturing an engine as compared to the cost of a new one was obtained from one of the companies that are already in the business of remanufacturing, Ghana Heavy Equipment Limited. Appendix A and B shows the list of spare parts and their costs used in remanufacturing a 12V140 Engine (twelve cylinder, 140mm bore V-engine) for one of its clients in the heavy equipment industry. This list of spare parts were part of the quotation given to the customer which also spelt out the labor and other miscellaneous costs, warranty terms and conditions, detailed strip down report, remanufacturing duration and the total cost of the repair in comparison to the cost of a new engine. It was observed that the average remanufacturing costs ranged from 26-40% of the cost of the new component. Fig 4.20 shows the state in which remanufactured components are packaged for delivery on completion obtained from Ghana Heavy Equipment Limited. The component is normally sprayed to its original color using the correct paint codes from the manufacturer after remanufacture. Spraying is done primarily to make it easier to detect leakages during the dynamometer test and also to add value to the finished product.

Source: GHEL, Quotation ref: GHEL/OBS/AGA/F15/2007 February, 2010.

Figure 4.20: State and condition of a Remanufactured Engine.

CHAPTER FIVE

EXPECTED BENEFITS OF REMANUFACTURING IN GHANA

Ghana, like other African Countries who have been officially identified to be in the business of remanufacturing stands to benefit in diverse ways from remanufacturing considering the large scale importation of used parts into the Country every year. As remanufacturing is a way to re-use waste cores which might otherwise be lying on a landfill, and create jobs, the benefits cannot be over-emphasized. Thirteen African Countries have forty five (45) Communities based Microsoft Authorized Refurbishing facilities (MARS) dealing in personal computers [23], with a long tradition of excellence and international trade of remanufactured goods. These Countries with their facilities are illustrated by table 5.1

TABLE 5.1: List of African Countries with Microsoft Authorized Refurbishing Facilities

COUNTRY	NUMBER OF MICROSOFT AUTHORIZED REFURBISHING FACILITIES(MARS)
Burkina Fasso	1
Kenya	2
Cameroon	1
Gabon	1
Liberia	1
Mauritius	1
Nigeria	10
Morocco	1
South Africa	20
Swaziland	1
Tanzania	3
Tunisia	1
Uganda	2

Source: UN ECA Conference, Nairobi, Kenya, April 12-24, 2010, document on Remanufacturing and Africa.

Conspicuously missing from the list is Ghana which goes to demonstrate the fact that there is a gap and an untapped potential which needs to be exploited. Direct and indirect jobs will obviously be created once these facilities are operational in these Countries listed above. Secondly, remanufactured Microsoft products will be readily available for use by consumers at reasonably lower prices. Global Industry analysts estimate the global market for remanufactured auto parts alone at $104.8 billion annually by 2015. It also estimates the global market for remanufactured ink jet and toner cartridges to be more than $5billion with more than 10,000 remanufacturers worldwide employing over 65,000 people [22]. Ghana can be part of this if we embrace the practice of remanufacturing.

5.1 REMANUFACTURING FACILITIES IN AFRICA

South Africa has the highest number of remanufacturing facilities in Africa followed by Kenya, Morocco etc. Ghana is not part of the list because no single commercial remanufacturing entity has yet been identified with the exception of the few companies in the heavy equipment industry whose remanufacturing activities are principally for their clients in the heavy equipment industry. Figures 5.1, 5.2 and 5.3 categorize the types of remanufacturing facilities in Africa in terms of the product lines. Ghana has not been identified to be part of the list.

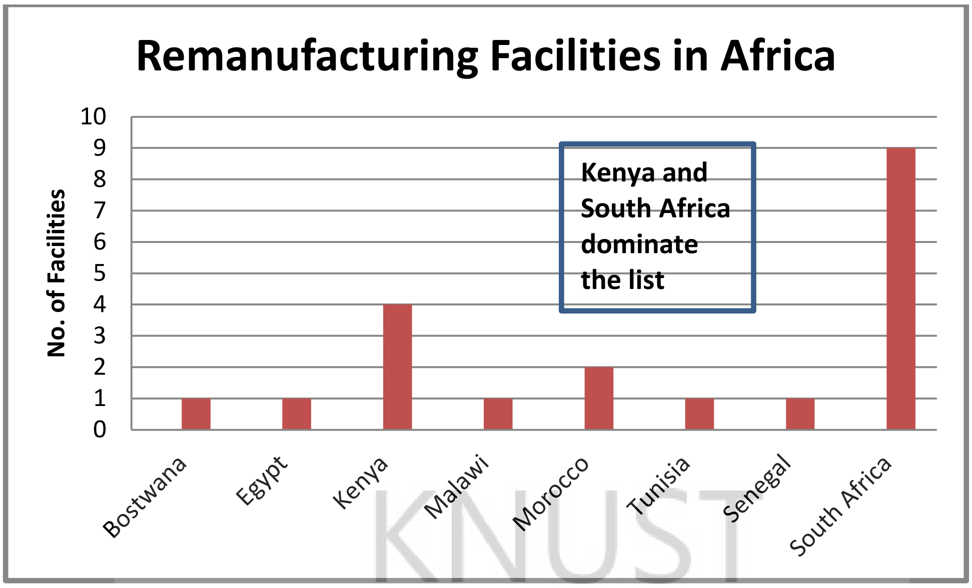

Figure 5.1: Remanufacturing facilities in Africa

South Africa again dominates the list in terms of automotive and engineering remanufacturing facilities in Africa indicated by figure 5.2 [22]. Some of the engineering remanufacturing facilities are fuel injector, construction equipment engine and other components remanufacturing. Remanufacturing practiced in Botswana, Egypt, Malawi and Morocco involve products like printer consumables other than automotive and engineering parts as indicated by figure.5.2

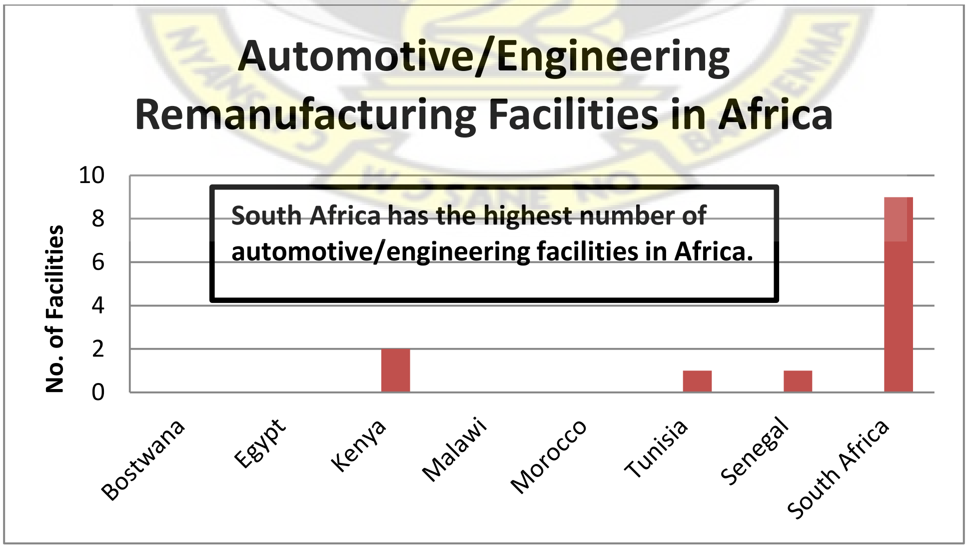

Figure 5.2: Automotive & Engineering Remanufacturing Facilities in Africa

Remanufacturing of large diesel engines is done Springbok, Fuel Injectors in Kwazulu and construction equipment in Johannesburg. Tunisia and Kenya are the only other Countries in Africa who are into remanufacturing automobile/engineering parts. Kenya remanufactures food processing equipment in Nairobi whereas Tunisia is into the remanufacture of automotive/engineering parts in Jemmal [22].

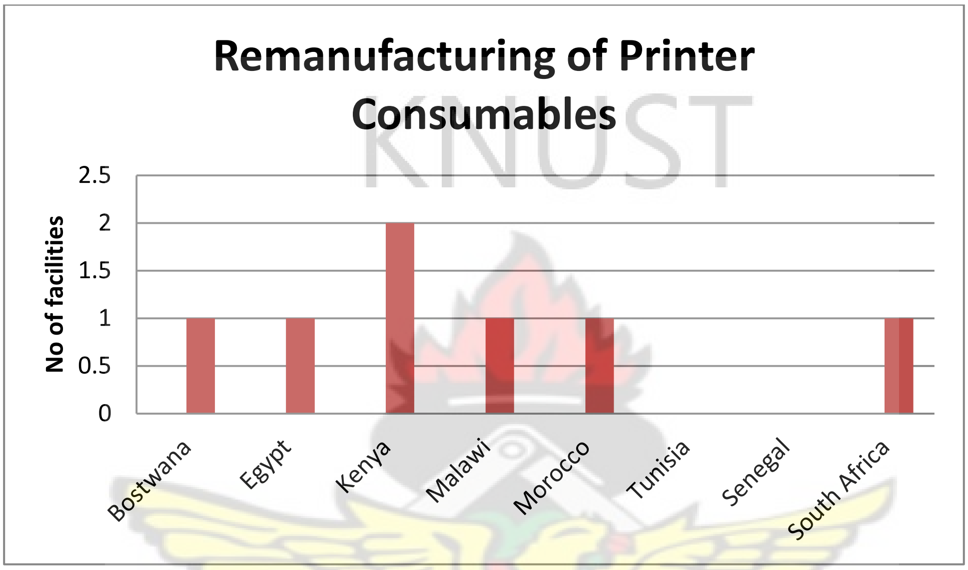

Figure 5.3: Facilities for Remanufacture of Printer Consumables in Africa.

Kenya has the highest number of facilities for the remanufacture of printer consumables followed by Morocco, Botswana, Kenya, Malawi, South Africa and Tunisia.

In Africa, remanufacturing is growing across the region with lots of intra-African trade in remanufactured goods whilst others are seeking to market their remanufactured goods worldwide [22]. Ghana has the capacity in terms of the human resource to be part of this evolving trend.

5.2 SUMMARY OF EXPECTED BENEFITS OF REMANUFACTURING IN GHANA

1. Remanufacturing offers the opportunity to re-use cores which might otherwise be thrown away, thus reducing landfill pollution from the disposal of these units into the environment.
2. Remanufacturing offers opportunities for the creation of skilled and unskilled jobs in various areas of skill and expertise. Each step of the process requires high levels of skill and competence. This requirement offers the opportunity for skills training and development.
3. Remanufacturing adds several life cycles to a product beyond its first life. This facilitates an enhancement in the productivity of the product and furthermore reduces environmental pollution.
4. Remanufacturing offers opportunities for industrial growth, thirteen African Countries have forty five (45) Communities based Microsoft Authorized Refurbishing facilities (MARS) dealing in personal computers. Considering the growing use of computers and computer accessories, these facilities are a necessity to reduce e- waste disposal.
5. Remanufacturing offers the opportunity to enhance the standard of living as good quality and reliable products can be obtained at reasonably lower prices compared to a new one.
6. Remanufacturing offers the opportunity to re-use original products, thus reducing dependence on low quality imitated products. There are a lot of imitated products on the market which are of low quality.
7. Remanufacturing promotes value for money, as warranty on remanufactured components ensures that quality, durable products are produced.

8. Remanufacturing offers opportunities for skills development because one can only be competitive in the industry by staying abreast with new technology.
9. Remanufacturing offers opportunities to reduce road accidents because used or junkyard parts may have had high usage, with poor or no maintenance history. Some of these components may have come from an equipment which might have been involved in an accident and may have hidden or unseen damage. Use of these parts exposes one to unseen risks.
10. Remanufacturing should be encouraged in Ghana because it offers the opportunity for the Country to compete with the technology driven developed world for skills and know- how and creates a competitive edge over its peers in the sub region who may not be involved in the practice.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Ghana, unlike other African Countries have not had the opportunity to exploit remanufacturing primarily due to the fact that not much awareness has been created about the potentials remanufacturing has to generate wealth through employment and skills development, which ultimately serves as a stimulus for economic growth. A case study of engine remanufacture was used to explain the best industry practices that will be required for the process because of the warranties involved. The study on its sustainability was conducted with data collection to determine the availability of cores and their remanufacturability and the results showed that 87,400,976.86 kilograms of used parts and 144,583 engine cores which are imported into the Country within three years to be used on 'as is' basis. This serves as a huge revenue base of GHC267,667,534.63 in cost, insurance and freight, (CIF) GHC50,252,918.32 in import duty, and GHC30,822,609.06 in other taxes, for example Ecowas Levy, EDIF fund etc. for the government. Data collected also showed that most of these imported units can be remanufactured as some of these cores are engines which are imported as whole units, ready for use. The study also shows that eleven African Countries are already in the business of remanufacturing with South Africa having the highest number of remanufacturing facilities in Africa followed by Kenya and Morocco. Components that are remanufactured in these facilities range from automobile and agro-processing units to toner cartridges. This shows that these African Countries have already taken up the challenge and exploiting this hidden giant for the benefit of their respective Countries. Ghana can be part of this evolving trend especially in this era of strong emphasis on the conservation of the environment.

6.2 RECOMMENDATIONS

The results of this research indicate that engine remanufacture could be targeted because of the larger percentage of imports in terms of weight which impacts negatively on the environment. These engine imports are generally from South Korea which tops the list. Due to the larger range of activities involved in engine remanufacture, it could provide a broad spectrum of job opportunities and skills development to artisans engaged in the practice. By adding more life cycles to a product beyond its first life, there will be the rippling effect of, reducing the incidence of inert cores lying on a landfill, thus helping to conserve the environment and turning perhaps costly disposal processes into product loops. Remanufacturing has the potential to create several skilled and unskilled jobs and also enhance the standard of living as good quality and reliable products can be obtained at reasonably low prices. It has again been observed that remanufacturing contributes in generating taxes for the government, helps in promoting value for money due to the warranties associated with the use of remanufactured products. Remanufacturing also has the potential to reduce road accidents as the frequency of use of used parts which may have come from an accident vehicle having undetected damage can be reduced.

This research is therefore recommended as a useful guide to individuals, institutions or corporate organizations or investors who might want to tap into this hidden economic prospect. As government will also benefit from taxes on imported cores, employment generation, environmental conservation, enhanced living conditions, and a possible reduction in road accidents, a case can be made by entrepreneurs to government for flexible business terms in the areas of tax on the importation of equipment for remanufacturing and other incentives to encourage the practice as pertains in the mining industry.

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APPENDICES

Appendix A: Komatsu SA12V140-2 Engine Remanufacture Parts List

ITEM	PART NO.	PART NAME	QTY	UNIT PRICE($)	AMOUNT($)
1	6215-41-4110	INTAKE VALVE	24	48.31	1,159.37
2	6215-41-4212	EXHAUST VALVE	24	51.70	1,240.85
3	6136-41-4520	VALVE COTTER	96	0.78	75.26
4	6210-11-7830	GASKET	12	28.07	336.84
5	6212-41-4540	SEAL	48	11.44	549.12
6	6215-11-6531	TUBE	2	150.83	301.66
7	6215-11-6542	TUBE	1	54.64	54.64
8	6215-11-6552	TUBE	1	51.60	51.60
9	6215-11-6560	JOINT BOLT	2	13.07	26.14
10	07206-30710	JOINT	10	7.26	72.62
11	6215-11-5150	EXHAUST MANIFOLD	1	996.43	996.43
12	6215-11-5140	EXHAUST MANIFOLD	1	790.98	790.98
13	6215-11-5920	PLUG	2	15.50	31.01
14	6215-11-8180	SENSOR	2	380.60	761.20
15	6151-11-8550	STUD	4	17.63	70.50
16	6114-11-5590	NUT	8	5.55	44.39
17	6138-13-4510	BOLT	4	5.39	21.54
18	6215-61-6690	HOSE	2	12.18	24.35
19	6215-61-4670	CLAMP	4	16.04	64.17
20	6210-81-4111	GEAR BOX	1	116.70	116.70
21	6130-61-6611	HOSE	2	10.36	20.73
22	07287-01912	HOSE	2	21.85	43.71
23	07285-00220	CLAMP	2	2.58	5.16
24	7861-92-2330	SENSOR	1	97.59	97.59
25	6215-21-8000	METAL ASS'Y	1	703.13	703.13
26	6212-31-2151	PISTON	12	445.80	5,349.56
27	6211-31-2033	PISTON RING ASS	12	123.27	1,479.18
28	6215-31-3041	METAL ASS'Y	12	43.49	521.92
29	04065-05220	SNAP RING	24	1.94	46.61
30	6215-51-1100	OIL PUMP ASS'Y	1	1,694.28	1,694.28
31	600-211-1231	CARTRIDGE	8	24.37	194.93
32	6215-51-6790	O-RING	10	4.57	45.70
33	6211-21-2220	CYLINDER LINER	12	203.27	2,439.19
34	6210-21-1490	BUSHING	14	21.97	307.54
35	08073-10505	SWITCH	1	28.23	28.23
36	6210-81-9210	PLUG	8	2.94	23.50
37	6215-51-1450	RING	1	17.20	17.20
38	600-211-1870	SPRING	3	33.62	100.86
39	6215-51-5690	GROMMET	2	5.76	11.52
40	6164-61-6340	O-RING	2	6.89	13.77
41	6215-51-5501	VALVE ASS'Y	1	696.55	696.55
42	6215-51-1701	VALVE ASS'Y	1	354.14	354.14
43	6215-71-5210	TUBE	1	36.93	36.93
44	6215-71-5220	TUBE	1	36.93	36.93

45	6215-71-5230	TUBE	1	36.93	36.93
46	6215-71-5240	TUBE	1	36.93	36.93
47	6215-71-5250	TUBE	1	36.93	36.93
48	6215-71-5260	TUBE	1	36.93	36.93
49	6215-71-5110	TUBE	1	36.93	36.93
50	6215-71-5120	TUBE	1	36.93	36.93
51	6215-71-5130	TUBE	1	36.93	36.93
52	6215-71-5140	TUBE	1	36.93	36.93
53	6215-71-5150	TUBE	1	36.93	36.93
54	6215-71-5160	TUBE	1	36.93	36.93
55	6215-71-4350	CLAMP	4	29.23	116.92
56	6215-71-5370	CLAMP	4	13.25	53.01
57	01010-30635	BOLT	8	0.31	2.48
58	6162-73-5510	CLAMP	14	33.77	472.72
59	6162-73-5520	CLAMP	14	26.46	370.37
60	01010-30625	BOLT	14	0.26	3.65
61	6215-71-5710	TUBE	1	49.84	49.84
62	6211-11-3130	CONNECTOR	12	82.76	993.11
63	6215-71-5580	TUBE	2	36.62	73.24
64	07270-20411	TUBE	8	10.59	84.74
65	6210-41-5620	CROSSHEAD	24	73.86	1,772.74
66	6215-81-5311	TUBE	1	53.17	53.17
67	6215-81-5320	TUBE	1	46.30	46.30
68	569-01-12492	BALL BEARING	1	42.11	42.11
69	561-01-62420	RUBBER	4	89.66	358.65
70	561-01-62410	RUBBER	4	53.32	213.27
71	6162-83-6911	VALVE	1	384.99	384.99
72	6215-81-5270	TUBE	1	57.82	57.82
73	6215-81-5281	TUBE	1	45.13	45.13
74	6215-81-5290	TUBE	1	33.11	33.11
75	6166-91-6160	JOINT	2	8.55	17.10
76	07206-31014	JOINT	3	9.69	29.08
77	6127-71-5710	JOINT BOLT	1	18.43	18.43
78	600-421-6630W	THERMOSTAT	3	64.74	194.22
79	6215-51-8140	HOSE	2	189.02	378.04
80	6215-71-5342	TUBE	1	27.27	27.27
81	6215-71-5331	TUBE	1	30.85	30.85
82	DK156605-4320	PLATE	2	115.09	230.18
83	DK156633-4900	BOLT	2	4.31	8.62
84	7861-92-3320	SENSOR	1	54.05	54.05
85	6215-61-3690	BELT	1	353.17	353.17
86	600-411-1601	RESISTOR ASS'Y	1	592.42	592.42
87	04120-21748	V-BELT	1	54.74	54.74
88	6215-81-5211	TUBE	1	34.76	34.76
89	06000-06219	BEARING	1	106.57	106.57
90	562-01-12742	SEAL	1	111.71	111.71
91	09940-00011	GASKET KIT	2	103.88	207.75
92	09940-00040	LUBRICANT	1	97.71	97.71
93	6215-K1-9901	GASKET KIT	1	3,208.12	3,208.12
94	6215-K2-9901	GASKET KIT	1	3,143.28	3,143.28
95	6215-61-1505	WATER PUMP ASS’Y	1	2,297.99	2,297.99

96	6215-71-8411	BOOT	2	44.37	88.75
97	6505-51-5031	TURBOCHARGER	1	4,125.88	4,125.88
98	6505-51-5041	TURBOCHARGER	1	4,125.88	4,125.88
99	DK487021-3620	VALVE ASS'Y	2	94.02	188.04
100	DK487026-2300	VALVE	2	14.93	29.87
101	DK487351-1000	WASHER	2	12.22	24.45
102	DK487026-2200	PLATE	2	30.98	61.95
103	DK487027-1500	SPRING	2	4.26	8.52
104	DK487351-0700	WASHER	2	0.49	0.98
105	DK487650-0101	SLEEVE	2	274.13	548.25
106	DK487001-4200	CYLINDER	2	215.15	430.29
107	DK487009-2000	PISTON	2	127.90	255.80
108	DK487010-4720	RING	2	53.51	107.03
109	DK016110-1610	RING	4	4.57	18.28
110	DK487013-2100	CONNECTING ROD	2	179.13	358.26
111	DK035620-6000	BALL BEARING	2	31.04	62.08
112	DK036202-0700	ROLLER BEARING	2	49.91	99.81
113	6210-16-1340	VALVE GUIDE	42	13.25	556.58
114	6212-11-1330	INSERT	24	13.95	334.90
115	6210-11-1321	INSERT	24	16.50	395.98
116	6215-K8-4001	GASKET KIT	2	285.81	571.63
		TOTAL			**$50,244.17**

Appendix B: Komatsu SA12V140-2 Injection Pump Remanufacture Parts List

ITEM	PART NO.	PART NAME	QTY	UNIT PRICE	AMOUNT($)
1	6215-11-3220	NOZZLE	12	108.61	1,303.27
2	DK150524-4100	SPACER	6	13.84	83.06
3	DK150550-5900	PUSH ROD	6	7.55	45.31
4	DK150562-6200	SPRING	6	9.08	54.50
5	DK150530-8700	SHIM	10	6.31	63.06
6	DK139634-0200	OIL SEAL	2	35.45	70.89
7	DK134563-2500	SLEEVE	2	64.94	129.88
8	DK139766-0000	O-RING	2	9.89	19.78
9	DK035302-0600	BEARING	2	7.48	14.97
10	DK020106-2040	BOLT	12	1.19	14.228
11	DK016650-2230	BEARING	2	34.41	68.81
12	DK031424-7120	VALVE	2	27.36	54.72
13	DK131041-0800	GASKET	22	0.68	1.37
14	DK134147-0520	PLUNGER	12	493.25	5,918.95
15	DK134563-4200	BOOT	2	27.61	55.21
16	DK134042-1400	GASKET	2	5.91	11.82
17	DK012206-1640	SCREW	24	0.55	13.13
18	DK134312-0000	GASKET	1	2.37	2.37
19	DK029621-7020	OIL SEAL	1	11.85	11.85
20	DK154371-5600	GASKET	1	3.05	3.05
21	DK155004-4900	SHAFT	1	87.07	87.07
22	DK139608-0200	SEAL	2	48.55	97.10
23	DK016610-2640	BEARING	1	5.54	5.54
24	DK028102-0010	BEARING	1	21.55	21.55
25	DK153251-0100	RUBBER	4	3.06	12.26
26	DK154206-2000	COLLAR	1	2.97	2.97
27	DK154327-3600	SPRING	1	4.94	4.94
28	DK154154-3900	SPRING	1	16.69	16.69
29	DK154371-3500	GASKET	1	3.27	3.27
30	DK139718-0200	O-RING	1	4.34	4.34
31	DK139716-0100	O-RING	1	10.59	10.59
32	DK016010-1640	SNAP RING	2	1.62	3.23
33	DK154371-3600	GASKET	1	3.30	3.30
34	DK139611-0200	SEAL	1	6.57	6.57
35	DK154400-7420	DIAPHRAGM	1	58.32	58.32
36	DK154352-0700	GASKET	2	2.83	5.66
37	DK152200-5420	PUMP	2	58.22	116.44
38	DK152115-0500	VALVE	8	4.79	38.30
39	DK029331-6030	GASKET	8	1.15	9.19
40	DK152116-0200	SPRING	8	1.27	10.18
41	DK029631-6060	O-RING	2	5.14	10.29
42	DK156829-0400	OIL SEAL	2	64.69	129.39
43	DK029340-8010	GASKET	2	1.04	2.08
44	6210-71-1160	GASKET	12	4.61	55.32
45	6210-11-7710	O-RING	12	4.53	54.34
46	07000-22021	O-RING	24	3.87	92.93
47	DK154200-6420	LEVER	1	278.47	278.47
48	DK154236-9620	LEVER	1	306.02	306.02
	TOTAL				**$9,386.61**

Appendix C: Countries of Origin of Used Engine Imports

Countries of Origin and Weights of Imports of Used Engines With/Without Gear Box (2008 – 2010)				
Country of Origin	Quantity (Metric Tonnage)			Grand Total (2008 -10)
	2008	2009	2010	
South Korea	932	1054	648	2634
Italy	387	391	513	1291
Belgium	271	329	309	909
United States	173	305	313	791
Netherlands	295	216	277	788
Denmark	198	225	243	666
United Kingdom	206	0	262	468
Spain	113	129	180	422
Greece	21	278	47	346
Japan	87	86	59	232
Canada	36	68	67	171
United Arab Emirates	29	44	89	162
Finland	20	40	3	63
Sweden	18	23	15	56
France	18	17	14	49
Ireland	5	7	29	41
India	22	4	5	31
China	9	14	7	30
Malaysia	14	12	3	29
Norway	19	4	5	28
Portugal	16	8	4	28
Korea Republic	7	0	12	19
Nigeria	2	2	14	18
Hong Kong	8	8	0	16
Taiwan	6	6	2	14
New Zealand	8	1	4	13
Togo	3	4	5	12
Australia	1	4	3	8
Kuwait	0	2	5	7
Austria	3	2	0	5
Senegal	4	1	0	5
Cyprus	1	2	0	3
Lebanon	2	0	0	2
South Africa	2	0	0	2
Switzerland	1	0	0	1
Ghana	0	0	1	1
Israel	1	0	0	1
Saudi Arabia	1	0	0	1
Singapore	0	1	0	1
Ukraine	0	0	1	1
Zaire	0	0	1	1
Grand Total (2008 -10)	206	3287	3140	6633