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Overhauling of Two Stage Reciprocating Air Compressor of a Conventional Locomotive-A Case Study

Ravi Shankar[1], Amit suhane[2], Manish vishwakarma[3]
Maulana Azad National Institute of Technology, Bhopal, India 462003

Research Scholar, Dept. of Mechanical Engineering, M.A.N.I.T, Bhopal, India[1]
Assistant Professor, Amit suhane, Dept. of Mechanical Engineering, M.A.N.I.T, Bhopal, India[2] Assistant Professor, Manish vishwakarma, Dept. of Mechanical Engineering, M.A.N.I.T, Bhopal, India[3]

Abstract- Reciprocating air compressor is the most widely used type of compressor found in many industrial applications and is a crucial machine in gas transmission pipelines, petrochemical plants, refineries, etc. Due to high pressure ratio requirements, reciprocating air compressor is commonly used in locomotives. After a period of life unexpected failures of internal components due to miscellaneous reasons occur, which affects the operating system performance. This paper presents a case study on reciprocating air compressor of a locomotive highlighting the associated problems, diagnosis and effective solutions supported by appropriate maintenance strategies for overhauling and repairing arising out due to frequent failure of parts. It is predominantly essential to establish the recommended clearances given for the various parts of the compressor. Based on dimensional measurement of compressor parts selection of repair and replacement becomes easy and it is best for economical point of view.

Keywords- overhauling, frequent failure, repair and replacement, dimensional measurement.

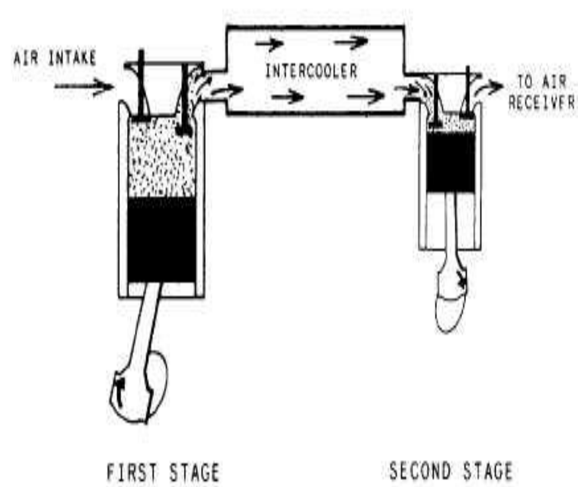

Fig.1.1 Example of an intercooler on a two stage reciprocating air compressor [17]

1. Introduction

An air compressor is a device facilitating conversion of machine power (usually an electric motor, a diesel engine or a gasoline locomotive) into kinetic energy by compressing and pressurizing the air, which, on control can be unconfined in rapid bursts Compressor is a device that extracts air from the ambiance and compresses it into a holding chamber [1]. In certain application such as air compression, multi stage double-acting compressors are said to be the most efficient compressors available and are typically Inter-cooling affects the overall effectiveness of the machine. While mechanical energy is applied for compression of air, after compression density of air increase due to which the temperature of the gas increases. After-coolers are installed after the last stage of compression to decrease the air temperature. As the air temperature is reduced, water vapor in the air is condensed, separated, collected, and exhausted from the system. Nearly all of the condensate from a compressor with inter-cooling is removed in the intercooler, and the remains in the after-cooler. Approximately all engineering systems, except those that supply process air to heat indifferent operations, require after-cooling.

Table 1.1 and Table 1.2 shows the technical specification of reciprocating air compressor (ELGI's TRC-1000) which is a horizontal, three cylinder, two stage and air cooled compressor. It is directly driven through an extended crankshaft by a connected electric motor and forms a mono block. The cylinders and cylinder heads are covered by an aluminum shroud and cooled by air drawn in by the common fan to cool the motor and the compressor.

Table1.1 Technical Data of Compressors Fitted on Conventional Locomotives (in mm)

Make	ELGI
Model	TRC 1000 MN
Type	Reciprocating, air cooled, "W" type and oil Splash Lubricated
Working Pressure	10.5 kg/cm^2
Displacement	1308 lpm
Free Air Delivery	1000 lpm
No. of Cylinders	3 (LP–2 & HP–1)
No. of Stages	2
Cylinder Bore and Stroke Length	LP – 100 x 85 HP – 60 x 85
Compressor Speed	980 rpm
Type of Valves	Disc valves
Direction of Rotation	Anticlockwise as Viewed from the non Driving End.
Type of Drive	Directly Coupled with Motor by a Resilient Flange Coupling
Crankcase Oil Capacity	Min.600 ml, Max. 1350 ml
Safety valve Setting on the Inter Cooler	6.0 kg/cm^2
Lubricating Oil Grade	SP-150 (IOC)/ Bharat 150
Overall Dimensions (L x W x H)	1050 x 7 x 965
Net Weight (without motor)	405 kg.
Motor Power	14 HP
Motor weight	185 kg Approx
Coupling Model	F x 136 Spring type Resilient Coupling
Suction Filter	Suction Filter Oil Capacity 350 ml

Table1.2 Important Sizes and Limits for ELGI TRC 1000 MN Compressor

Sr.	Description	LP	HP
1.	Cylinder bore (dia.)	100.001 to 100.000	60.01 to 60.00
2.	Piston (dia.)	99.855 to 99.845	59.92
	Gudgeon Pin Size (dia.)	20.000 to 19.995	18.000 to 17.995
3.	Diametrical Clearance between Cylinder and Piston	Normal 0.15 to 0.16 Max. 0.25	Normal 0.06 to 0.09 Max. 0.20
4.	Piston ring Butt clearance	Normal 0.08 to 0.25 Max. 0.40	Normal 0.08 to 0.25 Max. 0.40
5.	Piston ring Side play in Groove	Normal 0.04 to 0.08 Max. 0.12	Normal 0.06 to 0.09 Max. 0.12
6.	Connecting rod Small end needle Roller bearing Internal Diameter	20	18
7.	Clearance between Piston crown/top and disc valve bottom	1.4 to 1.6	1.4 to 1.6

1.3 Application of Air Compressor in Locomotive-Compressed air in locomotive is used for the locomotive brake system as well as for secondary systems such as, air conditioning, brake, horn, exhauster, windshield wipers, and radar head air cleaner.

1.3.1Air Conditioning- Fig.1.2 shows the layout of the air conditioning and heating equipment. Mainly modern passenger vehicles are provided with air conditioning and they will also have heaters in countries where the environment gets cold sufficient to need it. Here is the essential layout of an air conditioned coach, also ready with heating apparatus

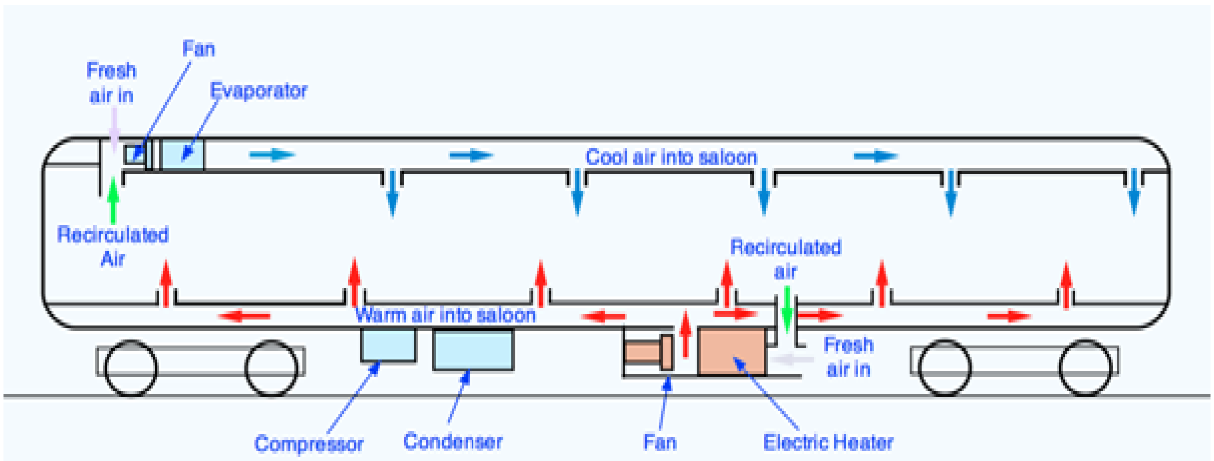

Fig.1.2. Diagram of typical passenger vehicle showing the layout of the air conditioning and heating equipment [17]

The air conditioner is designed to the split arrangement, where the condenser and compressor are mounted under the car base and the evaporator and fans are mounted in the roof. Sometimes there are two sets in the roof. The coolant since the condenser is passed to the evaporator in the roof throughout a connecting pipe.
The heater is a separate unit under the car floor, consisting of an electric resistance heater and a fan. Hot air is blown into the car by the fan, having passed through the heater from and under floor intake. This intake collects some fresh air and uses some recirculation air from inside the car. The same air intake collection is provided in the roof for the air conditioning fan in the roof.
Some car heaters on trains use resistance grids heated by the dynamic braking system. Waste energy generated by braking is improved into electric energy by the traction motors and this is fed into the heater grids.

1.3.2 Air Brake-This is the most ordinary type of train brake. It uses compressed air to affect the brake block or pad to the wheel and to control the process of the brake along the train. The compressed air is supplied by a motor determined compressor on the locomotive or train.

1.3.3 Exhauster-A pump, frequently electrically driven, which removes air from the brake pipe of a train prepared with the vacuum brake. Equivalent to the compressor on an air brake system, perform the same task as the ejector on a steam locomotive.

1.3.4 Train Horns-Train horns are operated by compressed air, typically (8.6-9.6 bar), and fed from a locomotive main air reservoir. When the engineer opens the horn valve, air flows throughout a supply line into the power assembly room at the base of the horn. It passes through a fine hole between a nozzle and a circular metal diaphragm in the power assembly room, then out through the flaring horn bell. The flow of air past the diaphragm causes it to pulse or oscillate against the nozzle, producing sound.

1.3.5 Wind Shield Wipers

A windscreen wiper or windshield wiper is a device used to remove rain, snow, ice and debris from a windscreen or windshield.

1.4. Compressed Air System in Locomotive

Fig.1.3 shows a typical arrangement for compressed air supply on a locomotive. The main items of equipment are a compressor, cooling pipes, an air dryer, a storage reservoir and controls.

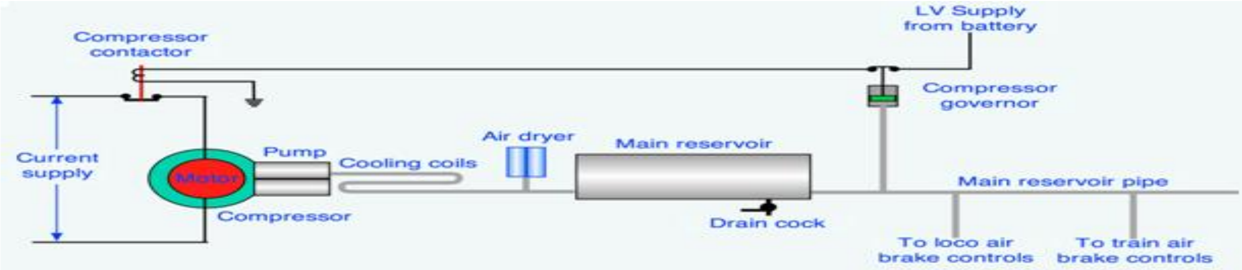

Fig.1.3. Schematic of compressed air supply on electric locomotive [17]

1.4.1 The Compressor

The compressor itself consists of a pump driven by an electric motor. The power from the motor comes from the on-board electrical supply or, at times, directly from the traction supply. On electric locomotives, the supply can approach from the transformer, by means of a rectifier and on a diesel locomotive, from the secondary alternator. On various diesel locomotives, the compressor is driven directly from the diesel engine by revenue of a connecting shaft.

1.4.2 The Pump

The conventional compressor pump was a piston in a cylinder. Later on two or three pistons were provided to raise compression speeds and give greater capacity. A few compressor manufacturers suggest rotary pumps, which are usually much faster and very much quieter than reciprocating pumps. They are however, usually more susceptible to mechanical faults and have worse capacity than reciprocating pumps. Development of quiet, reliable compressors continues.

1.4.3 Cooling

Compressing air makes it hot, so at least one set of cooling pipes will be provided. Some compressors contain two sets. The pumping is split into two stages and a set of cooling pipes is provided between each one, an inter-cooler and an after-cooler. Certainly, the cooling produces condensation, which collects as water in the air pipes and, combined with oil from the compressor lubrication, forms a slush which can quickly block up responsive brake valves. To overcome this problem, air systems are at the present time always provided with air dryers.

1.4.4 Drying

The air dryer consists of a pair of cylinders contain desiccant, which extracts the water and allow dry air to pass into the central reservoir. Water collected is automatically deserted once in each pumping cycle - the noise of the split open of water being discharge can often be heard at the end of the compressor's pumping cycle.

1.4.5 Synchronization

In a multiple unit train and when locomotives are coupled to function in multiple, the compressor process is usually matched. This means that if one compressor governor indicates low air pressure, all compressors will switch on together all through the train. When the previous governor indicates the air pressure is restored to its appropriate level, all compressors switch off collectively.

1.4.6 Control

The compressor is controlled automatically by a governor. The governor is planned to identify the point at which the compressed air height in the system has fallen to the lowest allowable level. As this happens, the governor switch associates close and send a low voltage (LV) current to a compressor contactor. The contactor is energized and closes a switch in the power supply to begin the compressor motor. When the pressure reaches the required upper limit, the governor opens and the contactor switches out the compressor motor. Every one compressor also contains an ON/OFF switch in the cab and there is typically a way of by-passing the governor in case something goes wrong with it.

1.5 Need for Modification in conventional locomotive checks and overhauling

The overhauling of reciprocating air compressor in locomotive is based on the visual monitoring and inspection. Visual inspection is a common method of quality control, data acquisition, and data analysis. Visual Inspection, used in maintenance of facilities, mean inspection of equipment and structures using either or all of raw human senses such as vision, hearing, touch and smell and any non-specialized inspection equipment. Visual inspection requires experienced and trained personnel to judge the effective working which is very often not achieved due to minute mistakes carried out in the selection of parameters. Any dimensional inaccuracy can lead to failure of whole system, therefore requiring an efficient and economical method for inspection. Chose dimensional measurement and quantify the size and shape of compressor parts. It involves lengths and angles as well as geometrical properties such as flatness and straightness. Dimensional measurement is of fundamental importance for interchangeability and global trade. It is how we ensure that things will fit together. Without global length standards as the basis for identical parts globalized engineering would not be potential. Dimensional measurement is also key to ensuring products perform as intended. This is very significant for safety critical parts and small clearance.

2. Literature review on Background of Reciprocating Air Compressor

A. Almasiv et.al [1] present a very well-organized technique of compressing just about any gas combination in large range of pressure, can make high head autonomous of density, and have many applications and wide power ratings. These make them necessary components in various units of industrial plants. In this paper best possible reciprocating compressor design regarding inter stage pressures, low suction pressure, non-lubricated cylinder, speed of machine, potential be in accuse of system, compressor valve, lubrication method, piston rod covering, cylinder liner matter, barring equipment, discharge temperature, cylinder coolant arrangement, presentation, flow, coupling, individual tools, condition monitoring (counting vibration, thermal and rod drop monitoring), gainful points, release and sound surroundings are presented.

Bartosz Kus et.al [2] Presented concept enable skilled compression for systems ranging from 0.1 to 5 MW of cooling ability, provided that the working pressures are minute, that is 30/10 bar. Achievement of the systems with higher working pressures, that is 77/30 bar is castigate in broad range of capacities owing to the extreme wind period losses, mainly marked in the systems with cooling capacities lower than 1 MW. In some belongings, chance of using longer motor should be analyzed. This may need extraordinary strategies for rotor dynamic issues or driving each impeller with individually mounted motor. It is observed that best specific speed of the compressor stage does not for time without end result in most favorable overall performance.

Dean L. Millar et.al [3] reported profitable large scale use cases of hydraulic air compressor; the technology has fallen into breakdown. This paper opens by clearing up that a lot of of the reasons for this are no longer applicable in a modern context. The working principles of hydraulic air compressors are reviewed and a hydrodynamic formulation is outlined so that hydraulic air compressor act can be assessed by revenue of reproduction. Reproduction consequences prove that hydraulic air compressor nearly offer a close-to-isothermal gas compression and so motionless offer huge scale gas compression effectiveness with lower energy use in comparison to modern-day inflexibility plant, even if decoupled from their opportunistic utilization of usual hydropower resources.

Fernando A. Ribas et.al [4] presents a critical review of special approach for reciprocating compressors thermal study. It is well standard that a main part of the ineffectiveness in minute reciprocating compressors used for family unit refrigeration is associated with thermal possession mainly reflect in terms of superheating. As a result the ability to optimize the compressor thermal presentation is vital to raise its efficiency.

Guilherme Marcelo Zanghelini et.al [5] defined a remanufacturing, recycling and land filling scenario subsequent European Directive on waste managing hierarchy. LCA method was applied to assess the potentials impacts on Global Warming, A biotic Resource reduction, Total rising Energy Demand and Land profession based on primary data composed by the Original Equipment Manufacturer (OEM). This case study indicates that the hotspot of this artificial goods system occurs in the use period due the high demand of energy all through its long life phase.

Houxi Cui et.al [6] focuses on the small non-linear model appreciation performance and minute sample number. As a result, the in sequence entropy, which is stretchy and tolerant to the non-linearity problem, is applied to analyze the feature of the signals. SVM is employed in the fault categorization because of its superiority in dealing with smaller sample problem. The information entropy skin texture and the optimization test of the SVM model are thorough analyzed. The trial shows the good act of the in sequence entropy SVM method in compressor valve fault analysis.

Jing Zhao et.al [7] presented the crankshaft of a large-scale reciprocating compressor frequently cracks since of the fatigue fail and the 1st and 2nd crank bearings often are injured due to tensional vibration. Such problems are handled by between the 2nd and 3rd shaft with two plate flanges in the form of interference fit assembling. Using numerical simulation, models are built for the two crankshafts with change. Modal study and dynamic response estimate of crankshaft system under different change projects are performed.

Kurt Pichler et.al [8] presents a novel advance for detecting cracked or broken reciprocating compressor valves under varying load conditions. The main idea is that the time frequency representation of vibration measurement data will show typical patterns depending on the fault state.

Vijay F. Pipalia et.al [9] investigation is concerned with the improving efficiency of two stage reciprocating air compressor by provided that water cooling resource, radiator coolant and ethylene glycol. The experiments of a two double-cylinder reciprocating compressor system with air, water and different inter-coolants were performed. The equations representing the volumetric and isothermal efficiency were solved and the predicted results compared with the investigational data and theoretical data of water, other cooling sources and air cooling showing good agreement.

Nan-Chyuan Tsai shows et.al [10] a novel Magnetically Levitated Linear Actuator (MLLA), mainly consisting of a Halbach magnetized moving-magnet armature, a cylindrical frame, a rod and electromagnetic (EM) poles, is presented and analyzed for linear compressors applications. The Halbach magnetized armature naturally generates a every so often distributed magnetic field which is interacted with that induced by the EM poles. Therefore, an axially reciprocating thrust force is induced that is inherently suitable for high frequency drive for linear compressors.

Ogundele et.al [11] investigates the maintenance of an air compressor used in quarries. The objectives of the research were achieved through the choice of a compressor. Reciprocating compressor was selected maintained as it will give the required volume of air at a very high pressure. It has capacity of 1200 m^3/hr which makes it to work with any types of pneumatic drilling machine at a very high pressure. For every 3000 hours and 6000 hours, the preventive maintenance is required.

Qiang Qin et.al [12] stand for a scheme for fault detection of compressor valves based on basis pursuit (BP), wave matching and support vector machine (SVM) is presented. BP is applied to extract the main vibration component in the signal and suppress background noise. Wave matching is a new feature extraction method proposed in this paper.

Van Tung Tran et.al [13] presents an approach to implement vibration, pressure, and current signals for fault diagnosis of the valves in reciprocating compressors. Due to the complexity of structure and motion of such compressor, the acquired vibration signal normally involves transient impacts and noise. This causes the useful information to be corrupted and difficulty in accurately diagnosing the faults with traditional methods. To reveal the fault patterns contained in this signal, the Teager–Kaiser energy operation (TKEO) is proposed to estimate the amplitude envelopes.

Vishal P. Patil et.al [14] conducted an experimental test rig has been built to test reciprocating compressors of different size and capacity. The compressors were tested with air as working fluid .The paper provides much needed information regarding the efficiency of the compressors operating under the same conditions with the same system parameters. This paper also reports on investigation carried out on the effect of pressure ratio on indicated power, isothermal efficiency of both compressors.

Yuefei Wang et.al [15] proposes a method of diagnosing faults in reciprocating compressor valves using the acoustic emission signal coupled with the simulated valve motion. The actual working condition of a valve can be obtained by analyzing the acoustic emission signal in the crank angle domain and the valve movement can be predicted by simulating the valve motion. The exact gap and closing the location of a normal valve is necessary.

Zhao Hai-yang et.al [16] attempt to improve the accuracy of dynamics response simulation for mechanism with joint clearance, a parameter optimization method for planar joint clearance contact force model was presented in this paper, and the optimized parameters were applied to the dynamics response simulation for mechanism with oversized joint clearance fault.

3. Overhauling Procedure of Reciprocating Air Compressor

Maintenance schedule proposed to perform an audit on the reciprocating compressor to determine the cause of failing. During these schedules, vibration measurements, visual inspections foundation are performed. Besides this, the maintenance planning, technical data use of wearable parts is reviewed. These comprehensive compressors schedule allow us to draw up the condition of compressor and propose potential solutions. The schedule showed that an overhauling of the reciprocating compressor was necessary to prevent wear of moving parts and auxiliaries would lead to an unplanned shutdown. Additionally, it was advised to renew the compressor foundation. To ensure its continuous operation, scheduling the overhaul becomes necessity.

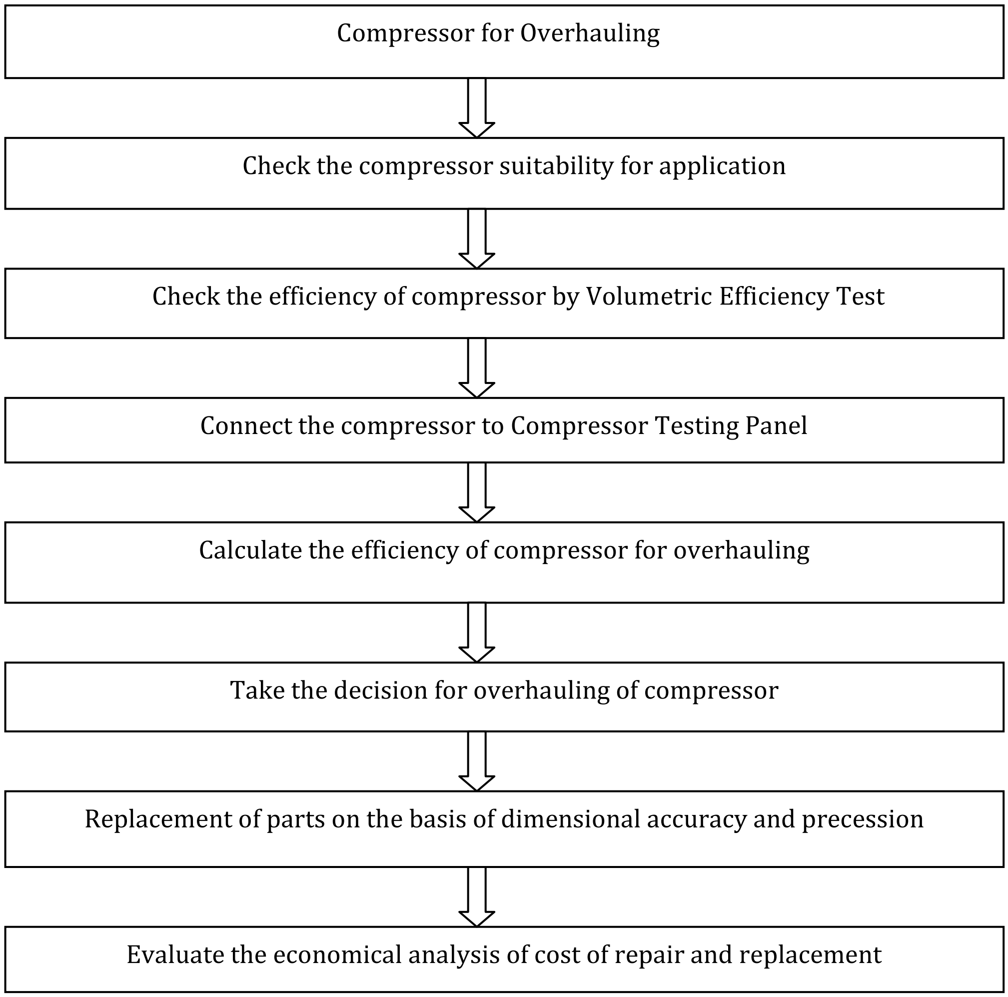

Fig.3.1 steps involved in overhauling of reciprocating compressor

3.1 Tests on Overhauled Compressor

Following tests are conducted on overhauled compressor

a. Temperature rise test
b. Leak back test
c. Vacuum test
d. Sub merge test
e. Volumetric efficiency test

a. Temperature Rise Test

This test shall be conducted with compressor running in free air with both suction and discharge valve open. Run the compressor till the temperature gets stabilized. The temperature will be recorded on the casing cover.

Maximum temperature rise at shaft seal shall not be more than 45^0C.

b. Leak Back Test

This test is in continuation of efficiency test. In this test immediately after attaining pressure is7 Kg/cm^2 in the reservoir, the compressor shall be stopped and pressure drop due to leakage shall be noted. Pressure shall be recorded at the end of 5 minutes and the drop in pressure shall not exceed 1.25 Kg/cm^2.

c. Vacuum Test

The compressor shall be run with suction valve closed and delivery valve open to atmosphere till a vacuum of 100 mm of Hg. below atmospheric pressure is created. The drop in vacuum level shall be recorded, after switching off the compressor.

d. Sub-Merge Test

The compressor shall be charged with dry air at 21 Kg/cm^2 pressure and submerged in water. Then check shall be conducted for any leakage; the same shall be attended and test repeated. No leakage through casing shall be permitted.

e. Volumetric Efficiency Test

The volumetric efficiency is an important parameter commonly adopted to quantify the performance of compressors.

The compressor shall be run with air at nominal speed of 1500 rev/min and time taken to attain a pressure of 8 Kg./cm^2 shall be recorded when the discharge line is connected to a reservoir f 100 litters capacity. The time taken to attain a pressure of 8 Kg/cm^2 cm in the reservoir should not be more than 8 minutes for ELGI compressors. Time to attain above specified pressures in the reservoir shall vary according to working speed of the compressor and atmospheric pressure also.

Fig.2.1 Compressor Testing Panel, Storage tank and Reciprocating air Compressor [18]

Several different measures of compressor efficiency are commonly used: volumetric efficiency, adiabatic efficiency, isothermal efficiency and mechanical efficiency. Adiabatic and isothermal efficiencies are computed as the isothermal or adiabatic power divided by the actual power consumption. The figure obtained indicates the overall efficiency of a compressor and drive motor. For the purpose of this study only volumetric efficiency was calculated using Equation

$$\text{Volumetric efficiency} = \frac{\text{FAD } (m^3/min)}{\text{CD}}$$

Where FAD is the free air delivered in (m^3/min) and CD is the compressor displacement.

$$CD = \pi/4 \times D^2/4 * L * S * n * X$$

Where D is the Cylinder bore in meter, L is the Cylinder stroke in meter, S is the Compressor speed in Rpm, X is 1 for single acting and 2 for double acting cylinders and n is the no. of cylinders.

After the calculation the efficiency of that compressor is 76.4%, so it is desire to overhaul to be done.

3.2 OVERHAULING (Periodicity – 18 Months)

The compressor should be completely dismantled by experienced staff. All the parts should be thoroughly cleaned, examined and repaired in a clean surrounding. Change all the items as per overhauling kit.

3.2.1 Removal of Compressor from Motor Coach

- Disconnect the lead connections from the junction box & earth lead connection.
- Before dismantling the unit from the carriage, make sure that the pipe lines are free from compressed air.
- Open the safety valves manually and open the drain cocks on the inter cooler and after cooler to release compressed air if any.
- emove the pipe fittings and then the air filter without spilling the oil.
- Remove the compressor unit by opening the foundation bolts. Use hydraulic trolley to remove compressor unit.
- Clean the unit externally.
- Bring the unit to auxiliary repair shop.

3.2.2 Dismantling Cylinder Heads

- Remove the nuts fixing the cylinder head to the cylinder.

- Use a mallet and tap the sides of the cylinder head and take it out.
- Decarbonizes and clean it thoroughly.
- Examine cylinder head for any damage.
- Use new gasket and spring washers below the nuts.

3.2.3 Suction and Delivery Valves

- Inspect all the parts for pitting, wear and distortion.
- Ensure that the locating pin is not worn out or bent or loose in vent seat.
- Renew the valve plates and spring plates in order to avoid fracture due to fatigue.
- Never use reconditioned valve plates.
- Valve seats should be reconditioned only by skilled personnel since air tightness.
- If valve seat, seating face is damaged it should be replaced.
- Fit the spring plates properly on the locating pin.
- Tighten castle nuts with correct torque and provide split pins.

3.2.4 Cylinders

- Remove the nuts fixing the cylinder to the crankcase.
- Check clearance between the piston and liner bore at right angles at three places, viz. at the top of the liner, middle of the liner and at the bottom of the liner.
- Measure the dimension of the piston at the skirt at 90° to the gudgeon pin bore.
- Check the dimensions of the HP cylinder. Replace it with a new one if damaged or worn out beyond limits.

3.2.5 Connecting Rods

- Remove the nuts fixing the side cover to the crankcase and remove the split pins from the connecting rod bolts and unscrew the nuts.
- Take out the connecting rod bolts. Use a mallet and lightly knock out the connecting rod cap.
- Take out the connecting rods through the crankcase opening for the cylinder.
- Provide new big end bearings and small end bush.
- When changing the bearings, ensure that oil holes are properly located and fully opened.
- Check for correct fit on the crankshaft.

3.2.6 Motor Mounting Bracket

- Unscrew the nuts fixing the motor mounting bracket to crankcase.
- Tilt & seat the oil pump fixing face of the crankcase on the floor.
- Unscrew the oil seal housing Allen screws and remove the oil seal housing and oil seal.
- Take out the motor mounting bracket and then the crankshaft from the crankcase.

3.2.7 Piston & Piston Rings

- Assemble the rings in their respective grooves and measure the side clearance using a feeler gauge. If it exceeds the specified limit, replace with a new set for each piston.
- Before assembling the piston into cylinder, ensure that the gaps of adjacent rings are in opposite direction. It controls oil leak and prevents compressed air leak to increase the efficiency of the compressor
- Clean the piston and the ring grooves thoroughly, after de-carbonizing it.
- Examine the gudgeon pin for damages.
- Insert the ring into the respective cylinder in such a way that it is in level with the top surface and then measure the butt clearance using a feeler gauge. If it exceeds the specified limits, provide new rings using proper tools.
- Knock out the gudgeon pin from the piston.
- Never forget to lubricate the rings before assembling.
- Replace small end bearing bush if piston is shaking on connecting rod.
- Take out the rings using a piston ring expander.
- The gudgeon pin should be push fit in the connecting rod bore.
- The piston should be assembled to the connecting rod and check for correct fit.
- The side marked TOP on the rings should face the top side of the piston.

3.2.8 Main Journal Bearings

- Check the bore size of the bearings and provide new bearing if it is worn out or exceeds the condemning limit.

3.2.9 Crankshaft

- Blow compressed air through the oil holes of the crankshaft and ensure that they are free from any dirt and blockage.
- The balance weights should not be removed from the shaft since reassembling may cause unbalance.

3.2.10 Oil Pump

- Dismantle the oil pump, clean it thoroughly and inspect all the parts.
- Replace all worn out or damaged parts.
- There should not be any end play for the rotors.
- There should be sufficient clearance between the rotors and the cover plate so that the rotors do not stick to the end cover.

- If there is excess of end play it can be corrected by lapping the outer face of the pump body.
- Ensure free movement of the inner rotor in the outer rotor.

3.2.11 Oil Filter

- Dismantle and swap all rubber seals and gaskets.
- Take out old filter part and fit new one.

3.3 Replacement of Parts- On the Basis of Dimensional Accuracy and precision

Replacement of parts of reciprocating compressor is based on inspection and accuracy of the dimensions of the wear out components. Then replace the worn out components.

Replace following components 100% irrespective of their condition.

- Piston rings
- Scrapper ring
- Suction and discharge valve
- Shaft seal assembly/O rings
- Gasket packing
- Half section bearing
- Self locking nuts
- Lubricating oil of correct grade.

Replace other components on dimensional condition basis. But these parts measurement and replacement is given here done on the basis of dimension measurement -for LP compressor dimensions

Table 3.1 Observation Table of LP Compressor

Sr.	Description	New Dimension of LP (In mm)	Name of Measuring Instrument with it Least Count (In mm)	Measured Dimension of LP (In mm)	Error in Dimension (In mm)	Conclusions
1.	Cylinder bore (dia.)	100.001 to 100.000	Bore gauge indicator (L.C=0.01)	100.07	0.07	Do not replace because Small change in dimension but within the limit
2.	Piston (dia.)	99.855 to 99.845	Vernier Caliper (L.C=0.02)	99.975	0.13	Change the piston because upper surface of piston is damage and cracks are generated
3.	Gudgeon pin size (dia.)	20.000 to 19.995	Vernier Caliper (L.C=0.02)	20.000	0.000	Do not change
4.	Diametrical clearance between cylinder and piston	Normal 0.15 to 0.16 Max. 0.25	Feeler gauge (Range from 0.01 to 1.00) (In mm)	0.0975	0.0525	Clearance with in permissible limit so do not change assembly
5.	Piston ring butt clearance	Normal 0.08 to 0.25 Max. 0.40	Feeler gauge (Range from 0.01 to 1.00) (In mm)	0.085	0.045	Within limit
6.	Piston ring side play in groove	Normal 0.04 to 0.08 Max. 0.12	Feeler gauge (Range from 0.01 to 1.00)	0.06	0.02	Do not change within limit
7.	Connecting rod small end needle roller bearing internal Diameter	20	Vernier Caliper (L.C=0.02)	20.025	0.025	Bearing dimensions extend and pitting occur so replace

These parts also measurement and replacement is given here done on the basis of dimension measurement -for HP compressor dimensions

Table 3.2 Observation Table of HP Compressor

Sr.	Description	New Dimension of HP (In mm)	Name of Measuring Instrument With It Least Count (In mm)	Measured Dimension of HP (In mm)	Error in Dimension (In mm)	Conclusions
1.	Cylinder bore (dia.)	60.01 to 60.00	Bore gauge indicator (L.C=0.01)	60.055	0.055	Do not replace because Small change in dimension but within the limit
2.	Piston (dia.)	59.92	Vernier Caliper (L.C=0.02)	59.935	0.015	Piston dimension with in limit and condition is better
3.	Gudgeon pin size (dia.)	18.000 to 17.995	Vernier Caliper (L.C=0.02)	18.000	0.000	Do not change
4.	Diametrical clearance between cylinder and piston	Normal 0.06 to 0.09 Max. 0.20	Feeler Gauge (Range from 0.01 to 1.00)	0.1075	0.0475	Clearance with in permissible limit so do not change assembly
5.	Piston ring butt clearance	Normal 0.08 to 0.25 Max. 0.40	Feeler Gauge (Range from 0.01 to 1.00)	0.0875	0.0275	Within limit
6.	Piston ring side play in groove	Normal 0.06 to 0.09 Max. 0.12	Feeler Gauge (Range from 0.01 to 1.00)	0.07	0.02	Do not change within limit
7.	Connecting rod small end needle roller bearing internal Diameter	18	Vernier Caliper (L.C=0.02)	18.0551	0.055	Bearing dimensions extend and pitting occur so replace

3.4. Economical Aspects of Overhauling of Reciprocating Air Compressor

A. Total cost of TRC 1000 MN reciprocating compressor is 120325 rupees

B. Total cost of first periodic overhauling which include the repair and replacement cost is given blow-

Table3.4 Description of Related Items

S.N.	DESCRIPTION OF REPLACED ITEMS	COST OF REPLACE ITEMS IN RUPEES
1.	4 No set of Rings	3800
2.	1 No top Gasket	1500
3.	4 Set of Valves	900
4.	2 No Fuel Filter	2500
5.	1 No Oil Filter	300
6.	19 Liters of Lubricant (Engine Oil)	2475

7.	Oil seal	120
8.	99.845mm Diameter Piston	9840
9.	3 Pieces of Air Compartment Big Piston Rings	6500
10.	4 Pieces of Air Compartment Small Piston Rings	5600
11.	Air Compartment Bearing	1400

Total fixed cost of items which are replaced=Rs. 34935
Overhauling Cost per worker per day= Rs. 450
Number of days required for overhauling=3
Number of worker required for overhauling=2
Total variable cost for overhauling operation=450*3*2= Rs. 2700
Total cost of overhauling=34935+2700
= Rs. 37635
So overall saving of money with overhauling when no need to replacement of compressor
=Actual price of compressor- Total cost of overhauling
=120325-37635= Rs. 82690

C. If overhauling is done on the basis of visual inspection than it is the probability of failure that some time the overhauling is done again because the desired efficiency of compressor is not gain. In this case some time wrong decisions are made then again overhauling is done to replace the replace the defective part. Then only some charges are made to perform the operation.
Therefore Overhauling Cost of worker per day= Rs. 450
Number of days required for overhauling=3
Number of worker required for overhauling=2
Total variable cost for overhauling operation=450*3*2= Rs. 2700

D. Total cost of measurement of parts of compressor
Number of worker required for dimensional measurement=1
Number of days required for dimensional measurement =2
Total variable cost for dimensional measurement=1*2*450= Rs. 900
In this way the total saving of money for accurate overhauling=2700-900= Rs. 1800

Conclusions

Based on the finding of case study, the conclusions are as follows:

1. Inspections and checks of dimensional clearance using appropriate gadget, tool, and devices, increase the accurate decision regarding replacement and overhauling as per need.

2. Appropriate overhauling strategy reduces the chance of uncertainetity in failure and extra maintenance cost.

3. Economical study perform on the reciprocating air compressor suggest good savings by implementing the modified strategy

4. Skills of labor help in time saving, which intern increase the productivity.

References

[1]. A. Almasi "Reciprocating Compressor Optimum Design and Manufacturing with respect to Performance, Reliability and Cost" (2009).
[2].Bartosz Kus, Petter Neksa "Oil free turbo-compressors for CO2 refrigeration Applications" (2013).
[3]. Dean L. Millar "A review of the case for modern-day adoption of hydraulic air compressors" (2014).
[4]. Fernando A. Ribas Jr., Cesar J. Deschamps, Fabian Fagotti, André Morriesen, Thiago Dutra, "THERMAL ANALYSIS OF RECIPROCATING COMPRESSORS – A CRITICAL REVIEW" (2008).
[5]. Guilherme Marcelo Zanghelini , Edivan Cherubini, Patrícia Orsi, Sebastião Roberto Soares . "Waste management Life Cycle Assessment: the case of a reciprocating air compressor in Brazil" (2014).
[6]. Houxi Cui , Laibin Zhang, Rongyu Kang, Xinyang Lan, "Research on fault diagnosis for reciprocating compressor valve using information entropy and SVM method, (2009).
[7]. Jing Zhao, Shijie Wang, "Analysis for Fatigue Failure Causes on a Large-scale Reciprocating Compressor Vibration by Torsional Vibration" (2014).
[8]. KurtPichler, EdwinLughofer, MarkusPichler, ThomasBuchegger, Erich PeterKlement, MatthiasHuschenbett, "Fault detection in reciprocating compressor valves under varying load conditions", (2016).
[9]. Vijay F. Pipalia, Mr. Ashok Thummar, Mr. Tushar Javiya, "Experimental investigation of overall efficiency of two stage reciprocating air compressor by way of inter-cooling" (2012).
[10]. Nan-Chyuan Tsai, Chao-Wen Chiang, "Design and analysis of magnetically-drive actuator applied for linear compressor" (2010).
[11]. Ogundele, O. J.Osiyoku, D. A. Braimoh J., and Yusuf, I. "Maintenance of an Air Compressor Used in Quarries" (2014).
[12]. Qiang Qin, Zhi-Nong Jiang, Kun Feng, Wei He, "A novel scheme for fault detection of reciprocating compressor valves based on basis pursuit, wave matching and support vector machine" (2012).
[13]. Van Tung Tran, Faisal AlThobiani, Andrew Ball, "An approach to fault diagnosis of reciprocating compressor valves using Teager–Kaiser energy operator and deep belief networks" (2014).
[14]. Vishal P. Patil, Shridhar S. Jadhav, Nilesh D. Dhas, "Performance and Analysis of Single Stage Reciprocating Air Compressor Test Rig" (2015).
[15]. YuefeiWang, ChuangXue, XiaohanJia, XueyuanPeng, "Fault diagnosis of reciprocating compressor valve with the method integrating acoustic emission signal and simulated valve motion" (2015)
[16]. Zhao Hai-yang, XuMin-qiang , WangJin-dong, LiYong-bo "A parameters optimization method for planar joint clearance model and its application for dynamics simulation of reciprocating compressor" (2015).
[17]. http://www.railway-technical.com/index.shtml