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Title of the paper: Integration of AI & ML with high-speed Compression Ignition Engine being used on Diesel Locos of Indian Railways.

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Abstract:

India has proved itself to be the major economy having the fastest growth the world over. By 2025, India's target is to the tune of $5 trillion economy. Owing to the Pandemic COVID19 period, the target appears to be more challenging. Currently, India's GDP is about $2.78 trillion. India's nominal GDP, estimated at about $2.74 trillion in FY20 has reduced to $2.66 trillion in FY21.

Strength of India's infrastructure is having direct & focussed attention on "Make in India". India has done a commendable job in handling the COVID-19 vaccination project indigenously for its 1.3 billion people. Definitely, **This is in line with the initiative of the Government for "Atmanirbhar Bharat".** The services sector has adversely suffered during Covid-19 pandemic. But the software services sector, an unexpected beneficiary, gained from the pandemic situation is the surging global demand for digital services, reviving client additions, top line growth and most important, hiring. NITI (National Institution for Transforming India) Aayog has mapped certain SDGs based on various defined indicators responding to national needs. **The Government is committed to ensuring "Sabka Saath, Sabka Vikas, Sabka Vishwas" in the spirit of the Sustainable Development Goals' motto of "Leaving No One Behind"**

Indian Railways is one of the largest networks for train operation and it is the fourth largest in the world. Since Railways are mainly concerned with train operation carrying passengers as well as freight services. As on 1st April 2021, the national rail network consists of 123,542 track km over a defined route of 64689 km with 7,325 stations.

For efficient train operation, Railways have to maintain a large fleet of rolling stocks hence importance of locomotive cannot be ignored.

These mainline diesel electric locomotives have definitely an impact on overall performance of the train operation.

In view of above, the efforts are made to integrate the functioning of high-speed compression ignition engines installed on high horse power locomotives working over Indian railways. This integration has been made possible with the help of Artificial Intelligence (AI) & Machine learning (ML) the latest technological approach. By using this technology, the railways are also

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capable to maintain punctuality of trains & reduce failures of locomotive to the extent possible.

Internal combustion engines have a major role for our civilization since the second industrial revolution. Today, Internal combustion engines stand at a critical intersection, seeking immediate breakthrough technologies to produce high-power and achieving near-zero carbon emissions targets.

Artificial intelligence (AI), particularly with the advances in machine learning (ML) and deep learning, out-performs humans in solving many highly complex real-world problems. In recent years, AI has revolutionized a huge number of disciplines. **Internal combustion engine is a complicated system that involves combustion, heat transfer, fluid dynamics, system control, and design, among other mechanisms, and thus provides a perfect yet challenging platform for AI applications. Testing and simulations of engine operations generate a huge amount of data that are utilized to train AI models. Meanwhile, applications of AI** models in model development, engine design/optimization, and control are still in their growing up stage. Interdisciplinary research on AI for internal combustion engines is needed to cover up this gap.

Here the emphasis is laid on the introduction of Microprocessor based Locomotive Control System along with the **MCBG /Microcontroller based governor which not only reduces /avoids engine failure but increases the operational efficiency of the locomotives in actual service.**

Key words: Artificial intelligence, machine learning, SDGs, heat transfer, fluid dynamics, Microprocessor, MCBG, efficiency, engine failures.

1.Introduction: Before going ahead, it would be better to throw some light on Artificial intelligence

1.1 Artificial Intelligence: Basically, artificial intelligence is the broad science of imitating human abilities, **machine learning is a specific subset of AI that trains a machine how to learn. AI focusses** with a commitment of genuine human to machine interaction. When machine is behaving like an intelligent person, request can be easily understood, data points connected easily and conclusions can be judiciously drawn. We are at a new level of advancement in technology in the AI field which is really fruitful in our lives.

Alternatively, Artificial intelligence is a field of computer science which makes a computer system that can imitate human intelligence**.** AI system need not be pre-programmed. On the basis of capabilities, it can be further sub-divided into three types:

- **Weak AI**
- **General AI**
- **Strong AI**

Presently, AI has a great focus on various disciplines. The future of AI is strong. It is said that stronger AI will be more intelligent than humans.

Intelligent machines, can be created with a larger concept of AI, that can stimulate human capability, thinking and behaviour, whereas, **ML is an application of AI which allows machines to learn from data without being absolutely programmed.**

There is a close relationship amongst AI, ML & deep learning and these are integrated at some level. AI has a long association with military science & statistics, along with contributions from psychology, philosophy, maths & cognitive science. AI initially set out to make computers more beneficial and capable of independent reasoning.

United States defence department had also taken keen initiative and increased the focus on training computers in order to imitate reasonings of human beings.

It has paved the route for the present automation and formal reasoning that we all observe in computers in this modern world. AI is on the path of changing the world. Actually, it already has our ability to consume and act on data because of advancement in computing, complex algorithms and intelligent analytical output.

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1.2 Machine Learning: Extraction of knowledge from the data comes under the purview of machine learning. It **makes the machines possible to learn from past data or experiences without being absolutely programmed"**

Machine learning **makes** a computer system **possible to** make predictions for taking some decisions using historical data without being absolutely programmed. A large amount of structured and semi-structured data is used so that a machine learning model can generate accurate result or confirm the actual output based on that data.

Machine learning works on algorithm and uses its own data to learn e.g. if machine learning model is created to detect pictures of tiger, it will only give result for tiger images, but if a new data is provided like image of a cat, then it will have zero response. Machine learning is also being used in various places such as Facebook Auto friend tagging suggestion, Email spam filter etc. ML can be divided into three heads:

- **Supervised learning**
- **Reinforcement learning**
- **Unsupervised learning**

1.2.1 Difference between AI & ML

S.No	Artificial Intelligence	Machine learning
1	Artificial intelligence enables a machine to simulate human behaviour.	Machine learning is a subset of AI allowing a machine to automatically learn from past data without programming explicitly.
2	The goal of AI is to solve complex problems.	The goal of ML is to permit machines to learn from data so that they can give correct output. It is meant to create machines which can perform specific tasks for which they are trained.
3	Intelligent systems are made to perform any task like a human	We teach machines with data to perform a particular task and give an accurate result.
4	Machine learning and deep learning are the two main subsets of AI	Deep learning is a main subset of machine learning.
5	There is a very wide range of scope in AI	Machine learning has a limited scope.
7	It is concerned about maximizing the chances of success.	It is specifically concerned about accuracy and patterns.
8	The main applications of AI is Online game playing, intelligent humanoid robot, Expert System, etc.	Machine learning is being used in various places such as for online recommender system, for Facebook Auto friend tagging suggestion, Email spam filter, Google search algorithms, etc.
9	On the basis of capabilities, AI can be divided into three types, which are, **Weak AI**, **General AI**, and **Strong AI**.	It is of three kinds e.g.; Reinforcement learning, Supervised learning**,** Unsupervised learning **etc.**

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10	It includes learning, reasoning, and self-correction.	In case of new data, it only includes learning and self-correction.
11	It completely deals with Structured, semi-structured, and **unstructured data**	Machine learning deals with Structured and semi-structured data.

1.3 Internal combustion engines: Since the inception of the second industrial revolution, internal combustion engines have powered on human interface. Presently I.C Engines are near critical path and there is an immediate requirement of specialised technologies to produce HHP in addition to fulfil the near Zero carbon emissions targets. It is one of the biggest challenges for the engine industry around the world.

Artificial intelligence (AI), particularly with the advances in machine learning and deep learning, out-performs humans in solving many highly complex real-world problems as indicated above. The Internal combustion engine mainly involves combustion, heat transfer, system control, fluid dynamics, and design, among other mechanisms and thus provides a critical platform for such applications. Simulations & Testing of engine operations have generated a large amount of data that can be utilized to train AI models.

Focus on the applications of AI in the field of internal combustion engines are of prime importance which include, but are not limited to:

• Engine design, including the combustion system, fuel and lubricant system, and after treatment system
• Development of data-driven operational performance for Internal combustion engines
• Fuel injection & heat transfer, etc
• Optimizations of internal combustion engines
• Engine speed control & other important aspects.

1.4 Micro controller-based Governor MEG -601 [MCBG]: MCBG-MEG-601 has been developed conforming to RDSO spec. No.MP.0.17.00.01 dated March 2002(Rev-01) amendment 02(June 2002).

Salient features of MCBG are enumerated as follows;

- Fundamentally, the basic function of the governor is to control the speed of engine based on corresponding notch position of the throttle.
- A micro controller-controlled DC stepper motor is used to control the fuel injection pump rack of diesel engine of the locomotive through an engine control linkage.
- Secondly, the important function is load control through an interface with E-type excitation system, to maintain a pre-set constant horsepower at each notch.
- It also maintains air inlet pressure corresponding to fuel supply to maintain air: fuel ratio.
- One of the important functions is low lube oil pressure shut down. It is done through an OPS (oil pressure switch). OPS is set for drop out & pic up pressures.
- Necessary provision for reduction of excitation during wheel slip is also incorporated which can be done through user settable parameters.

Vacuum Fluorescent Display (VFD) is continuously used to display status of various engine parameters. Configurations of system through user settable parameters and reading of error log can be managed on line on the locomotive itself by using a laptop, even when the engine is running. The equipment is modular in construction and it has functionally separated plug-in modules for ease of servicing.

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MCBG consists of two sub-assemblies namely:

(i) Control Unit (ii) Actuator Unit.

1.4.1 Control Unit: It is fixed on the short hood side wall just below the existing location of lube oil, fuel oil & booster air pressure gauges in the driver's cabin, or any other suitable location as per design features of loco. Control unit accommodates all necessary electronic circuits for functioning of governor. Plug in modules of control unit are as under,

1.4.1(a) Control card: It consists of a 16-bit micro controller; peripheral ICs and necessary system software for governor control. All the different cards in the system are integrated with control card.

1.4.1(b) Input card: Utilized for monitoring,

- Engine speed signal from tacho-generator.
- Position & pressure signals from the actuator unit.
- Notch input signals from throttle handle.
- All other high voltage input signals.

All the input signals are optically isolated surge protected and reverse polarity protected**.**

1.4.1(c) Motor Control card: It drives the stepper motor in actuator unit. Two identical cards are being used for this purpose.

1.4.1(d) Load & Clutch control: It is meant for driving the clutch in actuator unit and provides excitation voltage output for load control through an interface with E-type excitation system.

1.4.1(e)Display control card: Main attribute of the card is to display the data on Vacuum Fluorescent Display in **20-character x 4 line received from micro controller. The card has its own micro** controller to communicate with control card through serial communication.

1.4.1(f) Power Supply card: It is suitable for converting 72 V locomotive battery voltage to different low voltage supplies required by the system. Switches for various functions like over speed test, Reset/start operation & booster air pressure bypass.

1.4. 2 Actuator Unit:

Location of Actuator Unit is exactly on the same engine base as in case of already existing mechanical Governors.

- The Governor controls the engine speed, based on throttle position (known as notch), position of notches is controlled & selected by the Loco pilot on the control Desk.
- Tachogenerator or speed sensor is mounted on the Engine to indicate relevant engine RPM. Digital PID* control is used to calculate desired fuel rack position dynamically, based on the selected notch on throttle handle and measured Engine RPM.
- **Fuel rack of Diesel Engine is controlled by a stepper motor drive equipped in the actuator unit.** Load on the engine is controlled by the governor electrically through an electrical interface with the excitation system of Locomotive. Thus H.P at each notch is monitored at a pre-set level.
- A pressure sensor is equipped in the air manifold for measurement of booster (Turbo) air pressure. Movement of fuel rack is proportional to this pressure only to prevent incomplete combustion of fuel, black smoke, excessive engine temperature, fuel wastage etc caused by lack of air to burn the fuel.
- Engine L.O.P is continuously monitored. If the lube oil pressure is less than the specified pressure at each notch, engine is automatically shut down. Thus, consequential damages to the engine are avoided.
- Status of various engine parameters are continuously displayed on Vacuum Fluorescent Display (VFD).

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- Built in fault diagnostic facility takes appropriate action immediately and displays relevant fault message on the display board for information to the loco pilot. It also records the fault with date and time, to assist the maintenance crew /staff for analysis of the root cause.
- Configuration of the system through user settable parameters to ensure fine tuning of operation and reading fault messages of Error Log can be done, on-line on the locomotive, using a laptop even while the engine is running.
- The equipment is modular in construction and has functionally separated plug-in modules for ease of repair and maintenance.

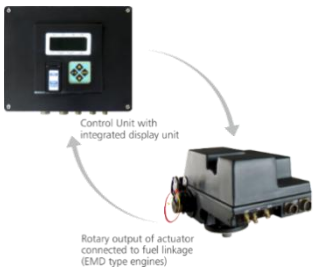

Fig.1 - Rotary output of actuator connected to fuel linkage (For EMD Locomotives)

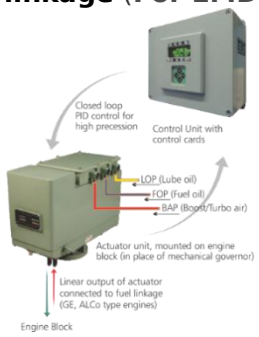

Fig. 2 - Linear output of actuator connected to fuel linkage (For GE/Alco type Locomotives)

1.5 Principle of operation:

In control unit the micro controller is continuously measuring the frequency signal from the existing Tacho-generator on loco.

(a) Engine RPM is calculated from this frequency signal. Required engine RPM is determined from the selected notch on throttle handle. Comparing these two RPMs in a PID control loop the micro controller drives fuel rack of the engine through the actuator unit, so as to adjust the engine RPM equal to the set RPM for the given notch. PID parameters can be optimised for each class of engines through user settable parameters using a laptop, so as to maintain stable engine RPM free from hunting.

(b) B.A.P is measured through a pressure sensor to limit the movement of fuel rack as a function of BAP. Thus supply of fuel to engine proportional to available air pressure is ensured. It is helpful in preventing,

(i) Incomplete combustion
(ii) Smoky exhaust gases
(iii) Excessive engine temperature
(iv) Fuel wastage.

A toggle switch is equipped on control unit to bypass this feature. In case of bypass, speed variation between different notches is linearly based on acceleration and retardation rates specified in user settable parameters.

(C) Load control output is provided to maintain constant horse power output of the engine at each notch. Load control is done by changing the excitation of generator field from maximum to minimum or vice versa at a rate specified in user suitable parameters. BAP linked load control facility is also available.

(d) Lube oil pressure (L.O.P) is continuously monitored. Provision of sensing wheel slip and reduction of excitation to minimum is available which can also be managed through a user settable parameter.

(e) Over speed Trip assembly:

A 3- position key switch is provided to ensure testing of over speed trip.

Ist position on key switch: Selects a built-in feature of MCBG to test electronic overspeed trip RPM < mechanical OST.

In this case engine RPM is gradually increased above 8th notch RPM, when engine RPM reaches a set RPM for

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electronic OST, the system shuts down the engine with proper display.

Second Position: Selects Mechanical OST where governor gradually increases engine RPM to maximum set limit and waits for a specified time. By this time mechanical OST device should operate & trip, even if it does not trip due to any reason- engine RPM reduces to idle. Display further indicates whether the test was successful/fail or needs adjustment.

(f) In addition to above, actuator unit is equipped with an electromagnetic clutch, which, during loss of power, turns off automatically and fuel rack is brought to no fuel position. It also gets deactivated in case of malfunctioning of the system**. This will close fuel rack and engine will shut down.**

A built-in fault diagnostic system continuously monitors the health of various peripherals.

In case of major faults, the engine is shut down automatically and displayed on display board with message. Fault is registered with time & date in error log for further maintenance /servicing. **This aspect is of vital importance for preventing the engine with heavy detrimental damages.**

1.6 User Settable parameters: Different parameters of the MCBG are user settable by using a laptop. The software displays the range and default value for any parameter that is selected for any minor modification. These values differ from loco to loco depending on the design features. **Laptop interfaces with MCBG through an RS- 232 serial port. These parameters can be set while the engine is running, which is very useful for initial turning of engine. List of parameters that are user settable is as follows;**

- **Notch wise engine speed.**
- **Notch wise minimum LOP for loco shut down.**
- Maximum permissible fuel rack at each notch.
- BAP wise -Fuel rack limit
- Setting of OST RPM
- Rates of engine acceleration & deacceleration.
- Load control minimum and maximum voltage & responsive time.
- Fuel rack position for cranking.
- Misc. parameters e.g., wheel slip sense enable &BAP linked load control enable etc.

1.7 Merits of MCBG:

- Control of engine RPM, elimination of hunting.
- Effective control for complete combustion of fuel, improvement in fuel efficiency and reduction of pollution.
- Load control interface with excitation system for constant horse power control.
- User settable engine parameters for optimizing performance for different class of locomotive as per design features.
- 16-bit micro controller-based design.
- Use of stepper motor for high precision position control of fuel rack.
- Digital PID control, requires no adjustment throughout its life & potentiometer settings are not involved.
- Engine status parameters are continuously displayed.
- Online fault diagnostics and fault message display.
- Error log with date & time .
- User settable RPM & LOPs levels for each notch.
- Functional plug-in modules for ease of maintenance /service.
- Electronic & mechanical OST RPM setting through key lock switch.
- Fail safe shutting down of engine is ensured in case of any major abnormality.
- No need of regular maintenance however schedules have been recommended for control & actuator unit to ensure improved performance of the system.

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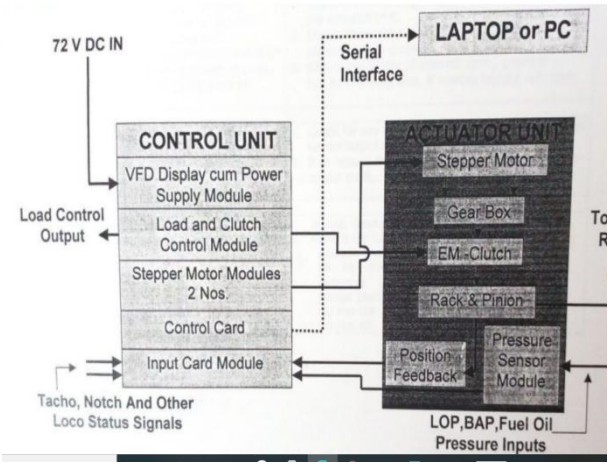

Fig 3.-SYSTEM BLOCK DIAGRAM

1.8 Maintenance schedule of MCBG

Sch.	Control unit	Actuator unit
Trip (20 days)	1.Ensure tightness of couplers on back panel of control unit. 2.Visual inspection of wire shoes & connections on MCBG terminal board at CP backside for any looseness or disconnected wires..	1.Ensure tightness of couplers provided on the actuator unit. 2.Ensure any possible leakage from the pressure sensor pipeline. 3.Ensure availability of external spring provided on fuel control shaft arm.
M4	1.Conduct rack calibration test as per laid down practice to ensure free movement of racks. If any racks are found sticky, re-test after lubrication.	1.check for any damage to the rubber bellow on the output shaft. 2.In case of damage to rubber bellow replace the bellow to avoid entry of dust on to the output shaft.
M24	1.Remove, clean and refit the unit. Replace (MCB MB gasket) if found damaged.	1.Unload, clean & refit the unit. Replace the following items if found damaged. (i)Actuator main cover gasket (ii)PRS box cover gasket (iii)Bellow AU (iv)Flange gasket (v) AU Mat-GB (vi) AU Mat-RP
M48	1.Remove, clean the control unit. 2.Visually inspect the individual modules for any damaged components . 3.Replace circuit breaker. 4.Replace gaskets as per companies guide lines. 5.Test the unit along with the actuator on simulator set up.	1.Clean the actuator unit after unloading. 2. Check & fill the grease. 3.Clean the clutch plates with thin cloth soaked with isopropyl alcohol. 4.Replace the gasket as per standard practice. 5.Check the calibration of pressure sensors for any damage /deviation.
M96	1.Replace all interconnecting cables with couplers and loco	

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	connecting cables. 2.Replace all pressure sensors. 3. Replace OSTA test key assembly. 4.Replace all push buttons (Reset/Start and Acknowledge.)	
NOTE: (a) Schedule attention listed here is telescopic type hence all lower schedules have to be followed along with a higher sch. (b)In case of any control unit and actuator unit are interchanged, auto fuel rack sensor calibration has to be carried out as per procedure laid down in governor maintenance manual for efficient control of fuel racks. (C)M2 & M12 Sch. are not shown as these are covered with next higher schedules.		

2.0 **Microprocessor Controller Unit**:

Medha's* Microprocessor based Loco Control System Type MEP 660 (Proprietary item of M/s Medha) being used for controlling diesel electric locomotives. This is an alternative to the E-type excitation system being used on WDM3 & other types of locomotives working over IR. This system is equipped for Excitation Control, Propulsion Control, Dynamic Braking Control, Wheel Slip Control, and Auxiliary Generator Control with digital PID controls.

Pic 1 MEP660- Display

2.1 Microprocessor MEP- 660 (Ver2.0) WDM3A & WDM3G Locomotives

Microprocessor based control system have been introduced on Diesel Electric Locomotives.

Microprocessor technology is new to engineers/operating staff and, therefore, it is necessary that proper knowledge about troubles which everyone faces during service of locomotives should be disseminated properly.

Microprocessor Control System is the vital part of Diesel electric locomotive. The system is recently introduced on Indian Railways for ensuring higher reliability & better availability of locomotives.

Proper knowledge of system and troubleshooting is necessary to ensure reliability & optimum availability of locomotive on line.

2.1.1 Introduction of excitation control system:

Excitation control system regulates the exciter field current through a transistor switch operated by the pulse width modulator basically a magnetic amplifier. The average current is decided by 'ON' to 'OF' ratio of PWM which is controlled by the mixer

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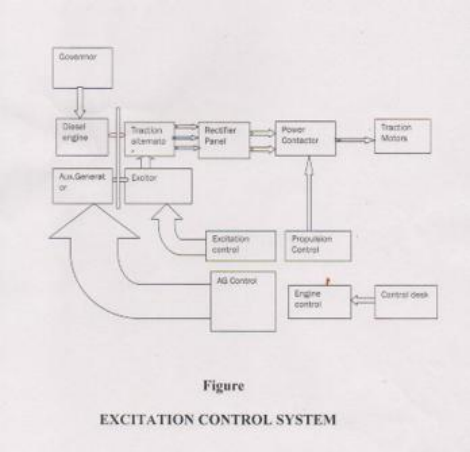


Figure

EXCITATION CONTROL SYSTEM

Fig.4: Excitation Control system

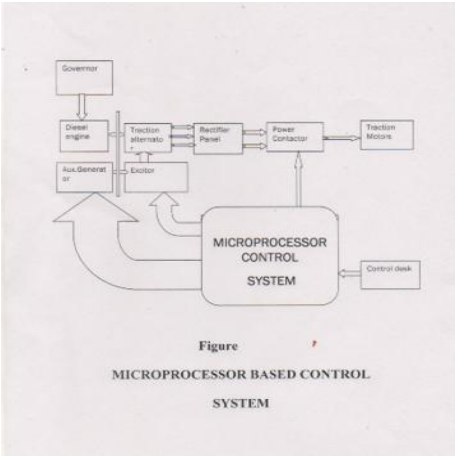
reference network basically a resister network with two saturable reactors and rectifiers. The mixer reference network receives proportionate feedback signals from TA voltage, TA current and engine speed. Based on the input signal levels, it sends a controlling signal to PWM, which controls the exciter field current and its output. The exciter output is directly connected to alternator field through GF contactor which is again controlled by propulsion control system. The traction alternator power is controlled to the required constant horse power at each notch.

3.0 Introduction of Microprocessor based Control system(ver2.0) for WDM3A/WDM3G Locomotives: The MEP-660 is a complete locomotive control system consisting of engine cranking, loco propulsion control, excitation control., auxiliary generator control & continuous monitoring of safety devices on the locomotives. Some of the improved features are the self-load test of the locomotives and inbuilt event recorder designed and developed as per RDSO specifications. MEP-660 loco control system is designed to replace the existing propulsion & E-type Excitation system. MEP-660 control system eliminates mechanical interlocking (sequential /timing) and uses microprocessor to control the locomotive through software logic.

Salient Features of Microprocessor Based control system (MBCS):

(a)Fault diagnostics: Microprocessor based system has the fault diagnostics capabilities. The system continuously monitors various operational parameters and checks for abnormalities in the functioning of various traction equipment.

The fault is displayed on the display unit along with restrictions imposed because of the fault. Fault code along with real time & date is logged in the Error Log Memory.



Figure

MICROPROCESSOR BASED CONTROL SYSTEM

Fig.5 Microprocessor based Control system

(b)Self-Diagnostics: This system keeps on monitoring its own modules and sensors, continuously for their healthy behaviour.

(c)Fault Tolerance: Fault tolerance capabilities are existing in this system for certain faults. In such cases the operation of the locomotive continues in the normal way and the fault is logged in error log with data pack for further analysis.

(d) Automatic fault recovery

(e) Short Term rating of traction motors

(f) Self-test to digital input and output

(g) Self: Load Box test

(h) Event Recorder

(I) In the short-term memory-Various data are recorded in one second interval and latest 45 Hrs data is available at any time for downloading.

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(II) In the long-term memory: - Only speed and distance along with date and time are recorded in 20 secs interval and Latest 225 days data is available at any time.

(i) Multi reset vigilance control device.

(j) Auto Flasher light

(k)Auto emergency brake system

Additional Features: -

1. Engine shuts down with failure of Crankcase breaker.

2. Limitation of power to 4th Notch with failure of RBB or Diode HOT.

3.Power de-ration from T3 setting to T4 setting (90 to 95° C): The engine power is derated by 20% of the notch power for every degree raised from 90° onwards.

4. 8th Notch RPM at hottest temperature: Engine RPMs are raised to 8th notch automatically by cutting of power for faster cooling of engine in case the engine reaches to T4 setting (95°C).

5. Low Idle feature: -When the locomotive is in Idle for more than 10 minutes, the engine RPM is reduced to 350 for reducing the fuel oil consumption.

Pic 2 -Diesel Locomotive

Brief Details of Engine:

Alco 251-C, 16 cylinder, 3,300 hp (2,500 kW) (2,430 hp or 1,810 kW site rating) with GE/ABB turbo supercharged engine. 1,050 rpm max, 400 rpm idle; 228 mm × 266 mm (8.98 in × 10.47 in) bore x stroke; compression ratio 12.5:1. Direct fuel injection, centrifugal pump cooling system (2,457 L/min (540 imp gal/min; 649 US gal/min) at 1,000 rpm), fan driven by eddy current clutch (86 hp or 64 kW at 1,000 rpm)

Conclusion: Thus, it is concluded that there is definitely the application of AI & ML with close integration with Microprocessor control based locomotive and Micro controller based governor with modified high horse power (HHP) turbo-superchargers because these system definitely contribute in reducing fuel consumption, maintaining proper air : fuel ratio, avoiding severe damages to engine power pack due to operation of over speed trip assy. electronically or otherwise by mechanical means, reducing exhaust emission by controlling incomplete combustion. These microprocessors governors & microprocessor control-based locomotive are supported by the design consideration and following points,

Durability, reliability and fuel economy(i.e specific fuel consumption) are the main considerations that limit the degree of supercharging of an engine.

- Because of the excessive heat generation and heat transfer,the valve overlap is usually designed greater in supercharged engines . The valve overlap may vary from approximately 80° to 160° of crank travel.
- Increased valve overlap permits greater time during which cooler air will flow past the valves and the piston crown. This cools the exhaust valve seat , the exhaust valves and the piston crown.Thus the thermal loading of cylinder head valves, valve seat & the piston crown is reduced to the extent possible.
- When inlet air is compressed, it becomes hot. When air charge leaves the compressor, it is at much higher temperature than ambient air. During supercharging, the temperature of air increases from 60° to 95° C. When air is heated, it expands and thereby density reduces. Because of this the mass of air entering the cylinder becomes lesser.This reduces availabilty of

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oxygen in the cylinder for combustion.Further supply of hot air to engine may increase engine operating temperature. As such charge is cooled by way of aftercooling to overcome this problem. In double discharge turbo of GE make, two aftercoolers are provided for cooling the charged air. However, it adds to the complexity of the system. **It has been proved that HHP locomotives engines are having improved BAP by 46.8 % say 47 % or more aas compared to conventioinal TSCs of ALCO make.**

The turbocharger may also be used to increase fuel efficiency without any attempt to increase power. It does this by recovering waste energy in the exhaust and feeding it back into the engine intake. By using this otherwise waste energy to increase the mass of air it becomnes easier to ensure that all fuel is burnt before being vented at the start of the exhaust stage.

The power of the engine can be increased by increasing the mean effctive pressure, this is being done by turbocharging.

- Volumetric efficiency of the engine is increased by 1.5% using turbochargiung compared to natural aspiration.
- Mechanical efficiency of the engine is increased by 12 % using turbocharger as compared to natural aspiration. Specific fuel consumption can be reduced by .020 Kg/KWH by providing turbocharging compared to natural aspiration.
- Turbocharging is economically better than the natural aspiration, because turbocharger can be driven by utilizing the exhaust gases. Air : fuel ratio is high in turbocharging as compared to natural aspiration. **Diesel knocking is reduced by providing TSC.**
- Design of turbosupercharger is basically based on following performance parameters;

(i) increased gas loading and thermal stresses, enhanced booster air pressure.

(ii) Durability, reliability and fuel economy (i.e specific fuel consumption) .

(iii) The valve overlap may vary from approximately 80° to 160° of crank travel. Thermal loading of cylinder head valves, valve seat & the piston crown is reduced to the extent possible.

(iv) During supercharging, the temperature of air increases from 60° to 95° C.

(v) Reduced exhaust emission, better torque characteristics, tractive effort is iomproved.

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