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Abstract : The unveiling of "Mission Gatishakti" marks a pivotal moment in India's transformation, with Indian Railways as the "engine of growth" to unlock the country's hidden potential. Therefore, It is imperative that swift and high-quality infrastructure projects, in which signalling systems play a vital role, are executed with utmost precision to realize the nation's aspirations. The interlocking principles of signalling systems ensure the safe and seamless movement of trains. As a result, System Integrity Testing (SIT) is considered the most critical and indispensable component of system installation. This ensures that all interlocking principles are appropriately embedded and that their specific correspondence with external gears is meticulously followed. The SIT of electronic interlocking (EI) systems is guaranteed by both the factory acceptance test (FAT) and site acceptance test (SAT). The use of cutting-edge technology enables us to leverage process-based automation tools that eliminate human errors and enhance the quality of installation. This study aims to review the challenges posed by the conventional method of SIT and examines the latest automation SIT tools for both FAT and SAT. Furthermore, it offers a compelling course of action to capitalize on these technological tools to improve the quality and integrity of installation while simultaneously expediting project execution. By embracing these best practices, the Indian Railways can join this revolutionary transformation.

सारांश : ''मिशन गतिशक्ति'' का अनावरण भारत के परिवर्तन में एक महत्वपूर्ण पल है, जिसमें भारतीय रेलवे देश के लिए ''विकास का इंजन'' का कार्य कर रही है। इसलिए, संकेत प्रणालियों की भूमिका अहम है और जल्दी और उच्च गुणवत्ता वाले बुनियादी परियोजनाओं को संपन्नता के साथ संचालित करना अत्यावश्यक है ताकि देश की आकांक्षाओं को पूरा किया जा सके। संकेतन प्रणालियों के संयोजन के नियम सुनिश्चित करते हैं और ट्रेनों की सुरक्षित और सहज गतिमान करते है। इसके परिणामस्वरूप, सिस्टम इंटेग्रिटी टेस्टिंग (SIT) सिस्टम इंस्टालेशन का सबसे महत्वपूर्ण और अनिवार्य घटक माना जाता है। यह सुनिश्चित करता है कि सभी संयोजन नियम सही ढंग से समायोजित हो जाएँ और उनका उनके बाहरी गियर के साथ उनके विशिष्ट संबंध का ध्यानपूर्वक अनुसरण किया जाए। इलेक्ट्रॉनिक संयोजन (EI) सिस्टम का एसआईटी ,फैक्ट्री एक्सेप्टेंस टेस्ट (FAT) और साइट एक्सेप्टेंस टेस्ट (SAT) दोनों द्वारा गारंटीबद्ध होता है। नवीनतम तकनीक का उपयोग, हमें प्रक्रिया आधारित स्वचालन उपकरणों का लाभ उठाने देता है, जो मानव त्रुटियों को नष्ट करते हुए स्थापना की गुणवत्ता को बढ़ाते हैं। यह अध्ययन इलेक्ट्रॉनिक संयोजन (EI) सिस्टम के सामान्य विधि से होने वाले एसआईटी के चुनौतियों की समीक्षा करने और एफएटी और एसएटी दोनों के लिए नवीनतम स्वचालन एसआईटी उपकरणों की जांच करने का उद्देश्य रखता है। इसके अलावा, यह एक दमदार कार्यक्रम पेश करता है जो इन तकनीकी उपकरणों का उपयोग करते हुए स्थापना की गुणवत्ता और अखंडता को सुधारने और परियोजना के निर्वहन को त्वरित करना संभव करता है। इन सर्वोत्तम व्यवहारों को अपनाकर, भारतीय रेलवे इस क्रांतिकारी रूपांतरण में शामिल हो सकती है।

Introduction:

The System integrity test [SIT] of the signalling system is conducted to ensure compliance with functional and safety requirements by simulating various states of signalling elements before bringing the signalling system into service. The present process of system integrity test is based on the certification of the testing personnel, which are error-prone due to human factors. For verification purposes, reliable pieces of evidence for the future reference are not preserved. More importantly, deficiencies observed at the later stage of commissioning and subsequent modification in application logic leave a possibility of incomplete SIT or delays in project execution. SIT is a time-consuming process (appx 10-12 routes/ day) and forms a critical bottleneck in project execution. Commissioning is frequently delayed due to a lack of sufficient block/non-interlocking time. This problem is exacerbated further during minor yard modifications when it is impractical to conduct a complete SIT due to lack of block as it severely affects train operation. Which, may seriously raise doubts over the integrity of electronic interlocking systems resulting in undesired or even unsafe signalling movements. Since the Indian Railways forms a critical part of "Mission Gatishakti", these delays distance us from realizing the dream quickly, safely and reliably.

SIT is the most critical activity in the commissioning of a signalling system. It consists of two components: Factory Acceptance Testing (FAT) and System Acceptance Testing (SAT). SAT can largely be defined as FAT + correspondence test. FAT is largely defined by the testing of system integrity in accordance with all of its interlocking principles. It ensures the safe working of station interlocking through complete testing which includes Control table testing, Cross table testing, Negative testing etc. SAT ensures the integration of outdoor gears with interlocking logic and principles. The process guarantees that all instructions, whether given or received, are communicated by the rightful authority, thereby ensuring effective communication and compliance with established protocols. SAT testing at the site prolong the non-interlocking period, which has the following repercussion:

a) Block-working, free home & starter signal has to be provided for the station, which requires additional wiring and work.

b) The points must be clamped and pad-locked during the yard's non-interlocking period for train movement. And for each test, the clamp and padlock must be removed, which takes considerable time. Further, each train movement restricts yard testing. Thereby, even for a smaller yard, at least one day's NI is required for SAT even for minor alteration work of gate interlocking or signal aspect changes etc.

SEM 19.8.8 mandates that SIT be performed on all new installations and modifications, as well as every five years on existing installations. Para 19.8.8.d-e mandates, testing of TOC after all functions are connected to EI during a non-interlocked period. Para 21.5.2 provides detailed guidelines for SIT of EI. With gained experience, SEM has included provision for alteration of the yard, which provides scope for only essential testing for the portions which are affected in modification with due precautions and care from field officials.

In the traditional relay-based interlocking system, the interlocking principles are hardwired through relays at the site, making on-site testing necessary. However, electronic interlocking (EI) technology has allowed for the pre-configuration of interlocking software, making off-site testing with the help of simulators feasible. By validating the system software integrity before installation, a comprehensive FAT can shorten the on-site SIT duration and enhance the installation's quality and integrity. With the gained confidence and adherence to necessary precautions and detailed procedures, the need for the selection table test may eventually be eliminated, requiring only on-site correspondence and functional testing. This could significantly reduce critical commissioning time and non-interlocked periods, particularly during minor yard modifications, without jeopardizing the system's integrity.

Currently, the process of conducting FAT & SAT testing is quite time-consuming, especially for higher routes. (Figure 1)

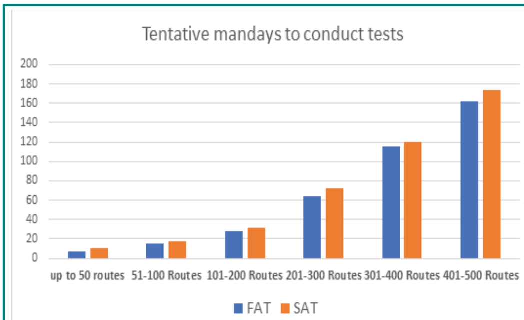
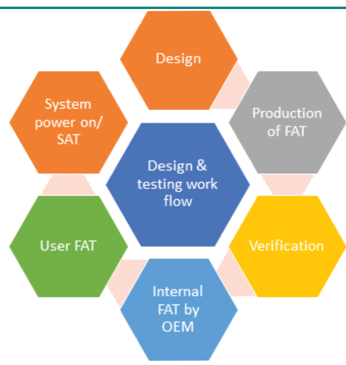


Fig. 1

Automated SIT offers a significant reduction in testing time compared to the current manual testing process. In particular, for stations with 50 to 500 routes, the time required to complete all tests for a single route after bypassing the two-minute time delay associated with route cancellation from a single simulation application is between 20 and 45 minutes. By running multiple parallel operations, further time savings can be achieved, allowing thorough SIT to be completed in a single day even for very large, complex yards.

A process-based technologically assisted SIT for EI systems, which creates evidence of testing and eliminates human errors is a need of the hour on Indian Railways. Several firms such as M/s Kyosan India Pvt ltd, M/s Efftronic India Pvt & M/s Sensedge have successfully demonstrated proof of concept in India, which has the potential to transform conventional manual SIT processes. Successful tests at Santragachi, Ghevra, Kanalus, Walaja Road, Jolarpetty, among others, have demonstrated the efficacy of these tools as a substitute for manual simulation. Moreover, it is feasible to develop a SIL2/SIL4 device with proper verification and validation processes.



Present process of signalling system design, wiring and testing on Indian Railways and limitations (fig.2)

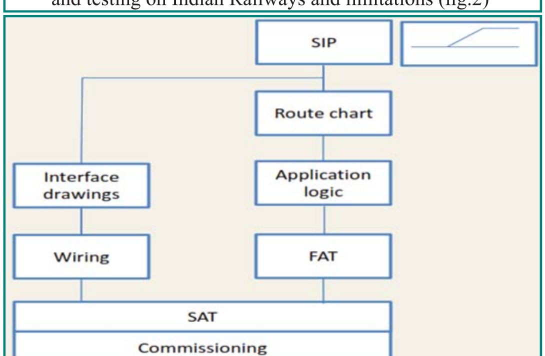


Fig. 2a

Challenges of Present Methods of Testing:

i. Manual testing is time-consuming resulting in project delays.

ii. Frequent changes in field requirements result in repeated FAT / SAT testing, delaying commissioning.

iii. No process-based comprehensive pre-test plan is prepared.

iv. Test procedure lacks uniqueness, except for common types such as negative tests.

v. No preservation of real-time test evidence makes it impossible to verify the completeness of the test later.

vi. Testing relies on the tester's skill, prone to human errors without a proper test plan.

vii. Lapses in manual testing may result in future operational/unsafe after triggering a specific scenario.

New practice of Automated Computerised System Integrity Test:

SIT assists in identifying errors in circuit design and circuit wiring. Signalling systems are amenable to automated computerized testing as the sequence of activities is precise and repetitive; results are predictable.

3 Stages of Development of Automated Computerized System Integrity Testing (Fig. 3):

Stage 1: Defining the tests in minute activities in sequence

Stage 2: Development of software which enables

i. Driving a specially made processor-based hardware for operations on the operating panel and changing states of signalling elements

ii. Creating TEST PLAN with expected results

iii. Retrieving simulator test results in the form of bit status for the signalling system's response.

iv. Comparing and validating test results to determine success or failure.

Stage 3: Development of hardware controlled by software from Step 2 to control VDU and signalling element states.

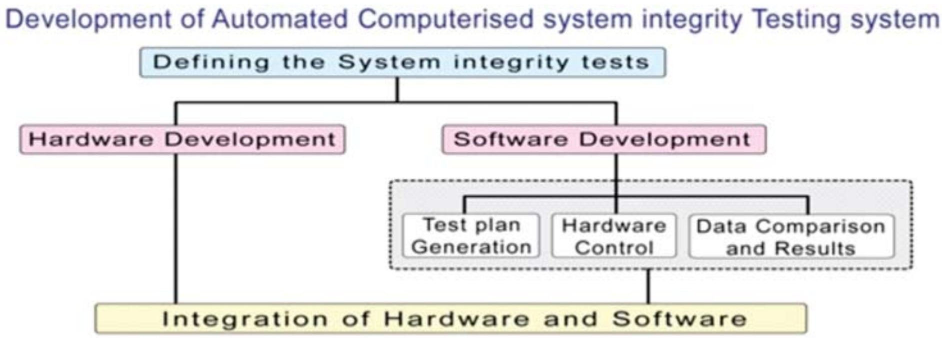


Fig. 3

Defining the Tests:

System integrity test consists of the following tests to ensure compliance of the signalling system to various safety conditions mentioned in the manuals, codes, and rules and regulations issued by the railway administration.

S.N.	Test Type	Description
1	Negative test	The status of signal-controlling functions in ST/LT, such as track, point, LX gate, slot, and crank handle, will be changed and the signal status change will be monitored.
2	One signal one train test	Upon clearing the signal, the first control track circuit is dropped and then picked up. Although the first control track circuit is picked up, the signal must remain in the danger state and display red.
3	Route release test for light engine movement	Upon clearing the signal, tracks are dropped to simulate light engine movement. The operation of route release relays at each stage is verified as per the specifications mentioned in ST/LT.
4	Route release test for long train movement	Upon clearing the signal, tracks are dropped to replicate long train movement, and the operation of route release relays at each stage is verified as per the specifications mentioned in ST/LT.
5	Route holding test	All route-releasing conditions are fulfilled except the picking up of the route holding track. Then, Route locking is observed.
6	Approach locking test	If the approach track is unoccupied, the route release will occur without any delay after route cancellation. However, if the approach track is occupied, route cancellation will occur with a time delay.
7	Red lamp protection	When a signal is cleared; an ahead signal red lamp proving relay is dropped. The previous signal shall change to danger.
8	Signal lamp cascading	After signal clearance, each OFF aspect supply is cut off. The signal shall change to a more restrictive OFF aspect.
9	Signal aspect sequence control test	After clearing all signals for a line, each aspect of a signal starting from the advanced starter is brought down to the next restrictive aspect. Changes in the aspect of signals in the rear are observed for their correct change as per STLT/aspect control chart.
10	Track locking test for points	Each controlling track is dropped and an attempt is made for operating the point. It shall not operate. However, emergency point operation shall be possible.
11	Crank handle locking test	An attempt is made to transfer the control of each crank handle locked by the signal when the signal is cleared. It is expected that the CH Control is not transferred.

12	LC gate locking test	An attempt is made to transfer the control of each LC gate locked by the signal when the signal is cleared. It is expected that the Gate Control is not transferred.
13	Route locking test	An attempt is made to operate each point which is locked by the signal, after clearing the signal. It is expected that point does not operate. Attempt is made to operate each point which is not locked. It is expected that the point shall operate.
14	SM Key Lock Test	Each Operation is Tested for SM Key Effectiveness.
15	Point Operation through Route Test	For Route Setting type Panels, controlling points are initially set opposite to the required condition. Then, the route is activated and the operation of points is checked to ensure they are set to the required position and locked.
16	Timers Test	Once a route is set, cancellation is applied and the time taken for the route to be released is observed. Each timer is tested separately.
17	Square sheet Test	A Main route is set and every test route is attempted to check whether it is locked / free. This is repeated for all the Routes. This test is done based on the Master Square Sheet provided by railways.
18	Route Checking Test	After a Route is set, in addition to Stage-wise Checking for UCR and ASR, all Non-control Functions (Tracks, Points, Crank Handles, Gates Indications) are checked. It is expected that the Signal Status remains intact.

Process of Testing:

Generation of Test Plan

a. Identify input/output bits based on TOC and test procedure, and create a generic software / simulator.

b. Identify signalling elements and their states to be changed for tests according to TOC and square sheet.

c. Identify buttons and switches required for tests based on VDU configuration.

d. Entering hardware details into the software for controlling panels and signalling elements.

e. Generate a test plan and manually verify the correctness of one test case for each test.

f. Obtaining approval for test plan from railways.

Sample of a SAT Procedure for Tests with a Simulator (Numbering Denotes Sequence of Operation)

S.N.	Test	Operation	Simulator sequence of operation	Output from simulator
1	Negative Test	3 Clear signal for selected route	1 Select route 2 Select negative test	4 Implement test by checking status of points, tracks etc. 5 Test result displayed
2	Square sheet test	3 Clear signal for selected route 6 Tester attempts the route suggested	1 Select the route 2 Select square sheet test 5 Tester PC prompts tester the next route to be attempted 8 Tester PC prompts tester the next route 1 to be attempted	4 Tester PC declares test result 7 Tester PC declares test result
3	Route release for light engine	3 Clear signal for selected route	1 Select route 2 Select route release for light engine	4 Implements the test by changing the statuses of tracks 5 Test result displayed
4	Route release for long train	3 Clear signal for selected route	1 Select route 2 Select route release for long train	4 Implements test by changing status of tracks 5 Test result displayed
5	Route holding test	3 Clear signal for selected route	1 Select route 2 Select route holding test	4 Implements test by changing statuses of tracks 5 Test result displayed

6	Approach locking test	3 Clear signal for selected route and cancel it 5 Again clear signal 7 Cancel route	1 Select route Select Approach locking Test	4 Test result displayed 6 Drops approach track 8 Test result displayed
7	Signal lamp cascading test	3 Clear signal for selected route	1 Select route 2 Select signal lamp cascading test	4 Implements test by changing status of signal lamps of signal 5 Test result displayed

Sample of Test Results:

Format of test result is given below:

Test name	Operation	Expected result	Actual result	Success
1A-A route Point negative test attempted	52 Point indication drop initiated: 52 NWKR Down 01/04/2011 09:28:51:0	52 NWKR Down 1A UCR Down 1A HR Down	52 NWKR Down 01/04/2011 09:28:51:312 1A UCR Up 01/04/2011 09:28:50:766 1A HR Down 01/04/2011 09:28:51:344	No

Explanation to the table contents:

Test name: Name of the test

Operation: Command given by test software to the test system.

Expected result: Signalling system's relay status change response as per the test plan.

Actual result: Signal system's relay status change response obtained from the data logger.

Success: Test results are evaluated by comparing expected and observed outcomes. A 'yes' result is obtained if there is no deviation, while a 'no' result is declared if there is a discrepancy.

Typical Deviations Observed in Sample Testing:

1. Omissions in circuit design: not implementing required condition
2. Commissions in circuit design: implementing additional [wrong] conditions
3. Wrong wiring: resulting in omission or commission of conditions or not meeting functional requirements
4. TOC corrections: certain conditions required to be provided in TOC but missed, still provided in the circuit design

Action plan for automatic FAT/SAT

FAT

a) The primary focus of the drawing office should be the preparation of the two critical inputs, SIP and RCC, in consultation with field officials.

b) The drawing office shall conduct automatic FAT using OEM's simulator and promptly correct any discrepancies encountered by the designer.

c) Conducting automatic FAT using OEM's simulator and making all necessary corrections is critical before considering FAT complete. The final automatic FAT result should be included in Technical System Application Approval (TSAA).

d) Conduct manual FAT at the factory premises with a simulation tool and a field setup. Define EI with Ports in advance and avoid any alteration during the FAT. Ensure all required interfaces are taken care of, including those for block working and data loggers. Provide spare ports for future modification work. This will ensure indoor works related to installation and alteration can be carried out independently of FAT.

SAT

Since the allocation of existing ports is not altered and is duly verified, and the interlocking provided by application logic has already been tested and certified by the drawing office as well as field officials, the integrity of the interlocking provided by application logic is verified. Additionally, the following functional and correspondence tests must be performed to ensure that EI systems communicate properly with field gears.

a) Correspondence of ports with the hardware ports as defined in the application logic.

b) Correspondence & functions of the gears introduced like signal, points, tracks, crank handle, LC gate etc.

c) Relay room wiring including cascading of signal aspect.

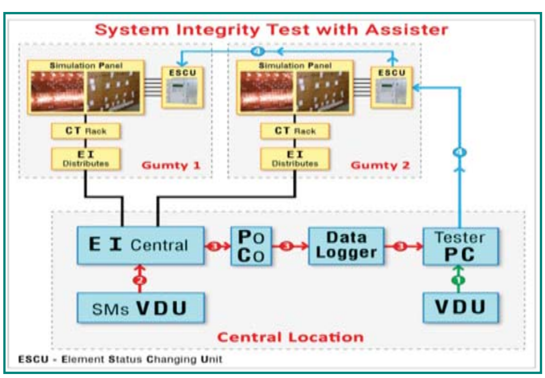
d) Block instrument hardware interfacing circuit with EI.

e) Wrong feed test (for newly added outputs).

f) Data logger interface.

Semi-automated SAT

Despite the need for manual procedures in ensuring the legitimacy of tools, successful semi-automated solutions to manual SAT have been tested at various locations, including Jolarpetti station, and have proven effective in determining system integrity by the concerned railways. This solution involves software with a station-specific test plan and evaluation tool, as well as an element station changing unit (ESCU) composed of miniature relays. The ESCU unit is responsible for controlling the I/O bits, such as track, points, signals, L-sing, etc. It automatically assigns functions to a simulated train operation that is approaching a station, with the software being run with the intervention of a single person. The software displays the progress of the test and delivers the results in the desired format, along with the timing of each individual function operation.



Advantage over Conventional Testing Process:

a) Reduces time of testing by at least 50%

b) Reduces effort -one person can conduct the test instead of multiple persons. Furthermore, testing official can see the status of remote cabins gears, which is not feasible in conventional system and requires human intervention.

c) Provides evidence for each test

d) Test result is evaluated automatically with improved correctness of testing

e) Completeness of testing monitored by railway official itself

f) Testing becomes simpler, especially for stations with distributed interlocking, as the status of signalling elements at gumties can be modified without human intervention at remote location.

g) The use of ESCU in the semi-automated solution eliminates the need for q-series relays, resulting in reduced wiring and relays. This simplifies testing and debugging, particularly in complex yards, and decreases the chances of errors in the simulation panel.

h) Modular reconfigurable setup, which can be reused for commissioning of multiple stations.

Challenges and Limitations to Automation:

Despite the potential benefits of automating manual testing of SIT through software or hardware solutions in the Indian Railways signalling system, there are several disadvantages and challenges to consider. The primary challenge that arises is the requirement for a significant upfront investment in the development of hardware and software. This investment may prove to be costly for smaller EI vendors, and it could also raise concerns among users regarding safety, potentially leading to the non-acceptance of the solution. Additionally, there may be a lack of technical expertise among staff to operate and maintain the automated systems, leading to potential delays and errors in testing. Another challenge is the need to ensure that the automated testing solutions are accurate and reliable, as any errors in the testing process could result in serious safety risks. Finally, there may be resistance to change from staff who are accustomed to manual testing procedures, and there may be a need for training and education to facilitate the adoption of new testing technologies.

Conclusion:

Indian Railways is at a crossroads in terms of implementing "Mission Gatishakti", where both speed and quality of execution are critical. Railways signalling ensures the safety of train movement. Achieving both can be a challenging task, but with the help of cutting-edge technology, it is possible. However, conventional manual signalling design and drawing processes, particularly during site testing, can cause significant bottlenecks. Fortunately, a proposed process-based system testing using advanced technological tools can drastically reduce testing time while simultaneously enhancing the quality and integrity of the installation. This frees up valuable time for railway officials to focus on preparing the correct input and improving the design of the interlocking system. With this approach, Indian Railways can make full use of the capabilities provided by electronic interlocking and ensure safe and speedy train movements.

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Inception of SiC (Silicon Carbide) Devices in Railway Application

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Abstract : Silicon Carbide (SiC) devices are widely believed to be the enabler of the next generation power electronic systems due to their superior characteristics such as low loss, high speed, smaller passive components and high temperature operating capabilities. SiC devices can operate at higher voltages, higher frequencies and higher junction temperatures than comparable Si devices, which results in significant reduction in weight and size of the power converter and increased system efficiency.

This paper will present a comprehensive review of the SiC power switching devices and their adoption in railway application in comparison with Silicon (Si) devices which are used in power converters of traction and auxiliary supply system in rolling stock.

सारांश : सिलिकॉन कार्बाइड युक्तियों को उनके उच्चतर गुण धर्मों जैसे कि निम्न शक्ति नुकसान, निम्नतर निष्क्रिय घटकों एवं उच्चतर तापमानों पर कार्य करने की क्षमता के कारण अगली पीढ़ी के इलेक्ट्रानिक प्रणाली के निर्माण में सहयोगी माना जा रहा है। सिलिकॉन कार्बाइड युक्तियाँ, सिलिकॉन युक्तियों की तुलना मे उच्चतर वोल्टेज, उच्चतर आवृत्ति और उच्चतर जंक्शन तापमानों पर कार्य कर सकती हैं, जिससे कि पावर कन्वर्टर के वजन एवं आकार में कमी तथा निकाय की कार्य क्षमता में वृद्धि होती है।

यह लेख सिलिकॉन कार्बाइड पावर स्विचिंग युक्तियों पर एक व्यापक समीक्षा प्रस्तुत करेगा एवं रेल अनुप्रयोगों में अभी प्रयोग किए जा रहे सिलिकान युक्तियों पर आधारित कर्षण एवं सहायक सप्लाई सिस्टम से उसकी तुलना प्रस्तुत करेगा।

Introduction:

Si power semiconductor devices have gone through many generations of development in the last 50 years and are approaching material theoretical limitations in terms of blocking voltage, operation temperature, and conduction and switching characteristics. Due to limited performance, the highest voltage rating of the state-of-art commercial Si IGBT has been 6.5 kV for the last 15 years. There are no commercial Si based devices with junction temperature capability above 175°C. These intrinsic physical limits become a barrier to achieving higher performance power conversion.

Compared with Si devices, Wide Band Gap (WBG) devices feature high breakdown electric field, low specific on-resistance, fast switching speed and high junction temperature capability. All of these characteristics are beneficial for the efficiency, power density, specific power, and reliability of power electronics converters. The WBG devices under rapid development and commercialization include silicon carbide (SiC) and gallium nitride (GaN) devices, with SiC mainly targeting high voltage high power (600 V, kilowatts or above) applications, and GaN for low voltage low power (600 V, kilowatts or below) applications. This paper focuses on SiC technology. SiC devices can improve and impact power electronics in several ways:

1) At converter level, through substituting Si devices directly or simplifying circuit topologies, SiC devices can improve converter efficiency, reduce cooling needs, and reduce active and passive component numbers and size, with their high voltage, low loss and fast switching capabilities.
2) At system level, SiC based converters can have better dynamic performance and more system functionalities as a result of their high frequency capability and high control bandwidth enabled by fast switching speed.
3) SiC can enable new applications, such as high-efficiency high-density solid-state transformers (SST) and high-speed motor drives. A number of commercial and research prototype converters using SiC devices have been developed with promising results on significantly improved efficiency and power density.

Structure of SiC:

Silicon carbide (SiC) comprises silicon (Si) and carbon (C) atoms. Each atom is surrounded by four different atoms in the form of a regular tetrahedron. SiC is a compound semiconductor with the densest tetrahedral arrangement. Compared to silicon, SiC has a wider energy gap where no electron states can exist (called a bandgap) between the valence band (i.e., an energy band filled with valence electrons) and the conduction band (i.e., an empty energy band in which electrons can be present). A wide bandgap provides a strong chemical bond among atoms and therefore a high electric breakdown field. SiC has an electric breakdown field roughly ten times that of silicon. The thickness of drift layer in SiC is approximately one-tenth of that in Si. This allows for dramatic reduction in conductivity loss and switching loss in SiC devices.

SiC has three times the band-gap width of Si which prevents the flow of leakage current and enables operation at high temperatures. Because of a strong atomic bond, SiC has greater lattice vibration and consequently conducts energy more easily than silicon. Therefore, SiC is a semiconductor material with good thermal conduction. The polytypes of SiC include 4H-SiC and 6H-SiC that are hexagonal crystal structures and 3C-SiC that is a cubic crystal structure. 4H-SiC is commonly used as a semiconductor material because it provides a better balance among electron mobility, dielectric breakdown strength, saturation velocity, and other physical properties than other polytypes of SiC.

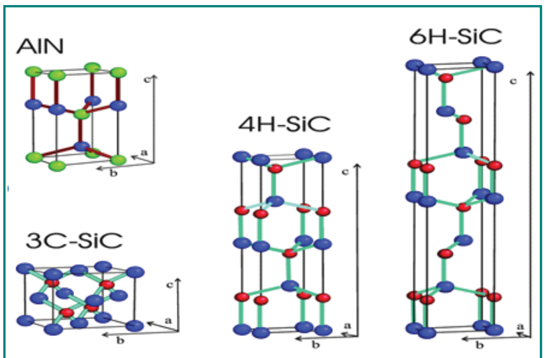

Fig. 1 - Unit cells of AlN (Aluminium Nitride), 3C-SiC, 4H-SiC and 6H-SiC

SiC Power Semiconductor devices compared to Si devices:

Fig. 2 highlights some key material properties of SiC semiconductor devices as compared to traditional Si devices. Generally speaking, for SiC material, the energy gap, breakdown electric field, thermal conductivity, melting point, and electron velocity are all significantly higher. These characteristics allow SiC semiconductor-based power devices to operate at much higher voltage, switching frequency and temperature than Silicon based devices.

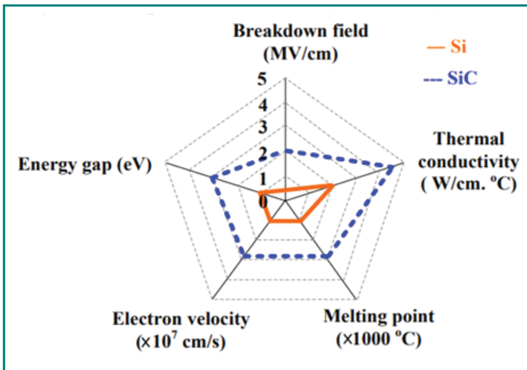

Fig. 2
Key Material properties of SiC Semiconductor devices

Evolution of devices:

Si based switching devices converted to Hybrid SiC then to All SiC devices. A Hybrid – SiC module is shown in figure below. It uses Schottky Barrier Diodes (SBDs). High speed switching can be realized with SBDs as they don't have accumulation carriers. The All SiC module is very compact and has high speed switching capability. It is possible to reduce the size of additional components like reactors due to high-speed switching.

Studies have been performed on 80 KW Traction Inverter with conventional Si devices and with All SiC devices and found significance changes in parameters/performance of Inverters.

Topology: Three phase inverter ; Synchronous rectification (SiC version) ; DC-link voltage: 400V DC; Current 480Arms (peak) 230Arms (nominal) ; Switching frequency: 16kHz

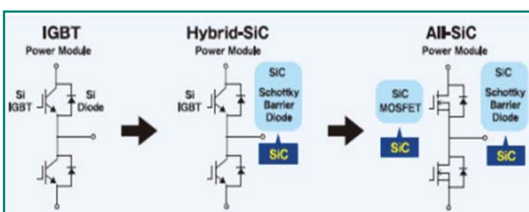

Fig. 3 – Evolution of devices

Size of Converter:

When SiC modules are used in converter, the reduction in the size of the converter is shown in the figure- 4 below. There is also a significant reduction in weight.

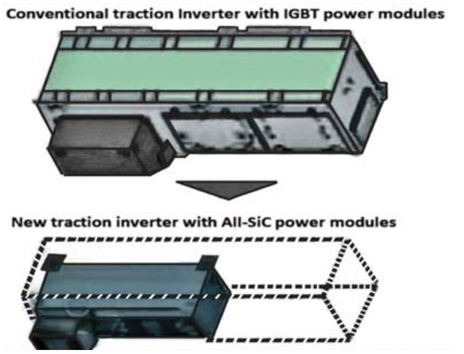

Fig.4 Comparison between size of converters

Key advantages of SiC based Traction inverter over Si based inverter:

In general, high density is a key goal for the SiC based converter in transportation application. High temperature capability may also be important in this application since the ambient temperature of transportation system is usually higher than room temperature. Also, by elevating the device junction operating temperature, less cooling requirement and high density can be realized.

- More than 50% module/package size reduction.
- Much smaller semiconductor area giving ultra-compact solution.
- >1.4% efficiency improvement and 67% lower loss.
- Lower losses at full load giving smaller cooling system.
- Lower ΔT (Tj-Tfluid) in the whole load range giving better reliability.
- 60% cooling system downsize.
- Much lower losses at low load allows smaller battery for same range.

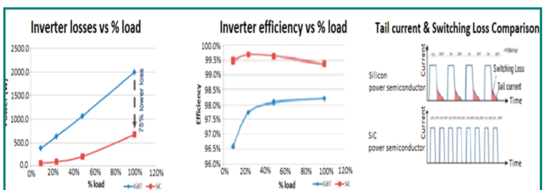

Fig.5
Comparison between Conventional vs SiC based devices

Status of SiC Devices: The summarized available information on SiC power devices, including device types, voltage/current ratings, status of commercialization, as well as the latest trend of SiC device development is provided in Fig. 6. It summarizes the status of SiC based power devices, including Schottky diodes, PIN diodes, MOSFETs, junction gate FETs (JFETs), IGBTs, bipolar junction transistors (BJTs), and thyristors with the voltage range from 400 V to 22.6 kV. It is observed that the low voltage (from 400 V to 1700V) SiC devices are becoming commercially available. Among them, the current rating per die approaches up to 100 A, and with multiple dies in parallel, state-of-art SiC power modules on market can deliver hundreds of amperes current. On the other hand, the high voltage SiC (referred here as 3.3 kV and above) are generally in developmental stages with limited commercial availability and small current rating per die.

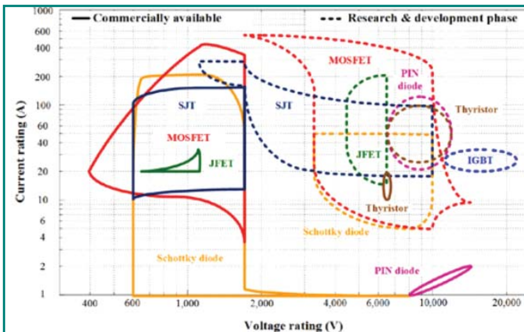

Fig. 6 – Status of SiC devices

Currently in Indian railways, application of SiC based converters is at nascent stages but few companies has started to use it in various applications such as ABB has offered the SiC based BORDLINE BC battery charger, which is compact, lightweight unit designed to charge the batteries and supply DC loads . M/s Alstom may offer SiC based auxiliary converter for train set project.

Challenges for SiC based power conversion system:

1. **Power module packaging:** As SiC power devices offer higher temperature capability, high temperature packaging becomes critical. Therefore, new packaging materials and optimized thermo-mechanical design are necessary for packaging.
2. **Paralleling of SiC devices:** Today, due to the limited current rating of single die of SiC device, development of SiC based power module with multiple dies in parallel is necessary for high power conversion system. The positive coefficient of on-state resistance of most SiC devices allows each paralleled device to achieve current sharing naturally. However, special attention must be paid to the dynamic current

sharing during fast switching transient since the switching behavior of SiC devices is highly sensitive to the mismatch of parasitics in the switching loop (e.g. gate loop inductance). Accordingly, parasitics of each die should be carefully controlled via packaging and layout design to ensure good dynamic current sharing.

3. **Capacitive coupling effect:** Inside the power module, a layer of insulating material is used to separate the SiC devices from the electrically conductive baseplate. Thus, a chip to baseplate capacitance is formed . Via the baseplate of power module, this coupling capacitance is paralleled with SiC devices, which increases their equivalent output capacitance, and worsens the switching behaviour.
4. **Design of Gate drive:** Power modules based on SiC materials enhance efficiency, but also introduce oscillations to switching cycles due to the higher di/dt. While the transistors are robust and can handle the oscillations, the radiated and conducted noise becomes a nuisance for components or circuits downstream.
5. **EMI effect:** SiC devices with high switching frequency operation provide the opportunity to shrink the size of passive EMI (Electro-Magnetic Interference) filters. However, electromagnetic noise will also tend to concentrate in the high frequency range and also at high frequencies, the coupling effect of filter components through capacitive path and inductive path becomes worse increase filter design difficulties due to the non-ideal behaviours of passive components at high frequencies.
6. **Cost:** Component cost considerations of SiC MOSFET vs IGBT (1200V)-

- Today the price of SiC MOSFET is 4 – 4.5x relative to IGBT
- Near Term (2 – 3 years) - 2.5x cost reduction may be due to improvements in SiC devices and higher volume
- Long Term (5 – 10 years) - Further development and larger wafer diameter needed to continue to bring cost down

Conclusion:

1. With smaller size, lower loss, faster switching, and higher temperature capability, SiC devices can improve power conversion systems in several ways: by direct substitution of Si devices in existing circuits for improved efficiency and power density, by simplifying the circuit topology for reduced complexity and further enhanced power density, and by enabling system configuration modification for overall system power density improvement and lower cost. Because of these properties, high capacity traction converter may be designed to accommodate in rolling stocks which are having space constraint due to IRSOD.
2. With faster switching, higher temperature, and smaller size, SiC also raise new design and application challenges. Gate drive and protection need to be faster and more adaptive. Loads can interfere with converter switching, therefore may require additional filters. High temperature and fast switching also demand better device packaging. Other challenges include thermal management, EMI filters design, sensors and control. However, the design and application methodology for SiC power electronics will remain an active research area for the foreseeable future.

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Comparative Study of Specific Fuel Consumption (SFC) in ALCO(WDG-3A) and EMD(WDG-4) Class of Diesel Engine at Engine Test Bed of DLW, Varanasi


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Abstract : Out of Various parameters of Diesel Electric Locomotive, SFC is one of the most important variants to evaluate performance of Diesel Engine. By SFC, we mean fuel consumed by an Engine for delivering unit Power. Lower values of SFC indicate towards more Efficient Engine. Traditionally, ALCO Locomotive Engine used to have SFC of 166gm/BHP which has improved to 152 gm/BHP over the years by consistent effort of RDSO/Lucknow & DLW/Varanasi. To meet increased traffic demand, HHP Locomotive were inducted in Indian Railways in 1998. Although, thermal efficiency of 3600 HP ALCO Engine is better than 4500 HP EMD Engine; mechanical efficiency of EMD Locomotive has proved to be better because of adoption of MCBG Governor, modified TSC, IGBT based AC-AC Traction System, high speed AC Motors etc. In this paper, an attempt has been made to analyze variation in SFC due to operation of different notches in engine Test Bed. Rigorous testing of Engine at different Load in ETS ensure improved performance of Locomotive, plying all over varied Terrain of Indian Railways.

सारांश : डीजल लोकोमोटिव के विभिन्न मापदंडों में से, इंजन के प्रदर्शन को आंकने के लिए एसएफसी सबसे महत्वपूर्ण वेरिएंट में से एक है। एसएफसी से हमारा तात्पर्य यूनिट पावर देने के लिए इंजन द्वारा खपत किया गया ईंधन है। एसएफसी का कम होना अधिक कुशल इंजन की ओर संकेत करता है। परंपरागत रूप से, एल्को लोकोमोटिव इंजन में 166gm/बीएचपी का एसएफसी होता था, जिसमें पिछले कुछ वर्षों में आरडीएसओ/ लखनऊ और डीएलडब्ल्यू/ वाराणसी के लगातार प्रयास से 152gm/ बीएचपी तक का सुधार हुआ है। बढ़ती यातायात की मांग को पूरा करने के लिए, एचएचपी लोकोमोटिव को 1998 में भारतीय रेलवे में शामिल किया गया था। हालांकि, 3600 एचपी एल्को इंजन की ऊष्मादक्षता 4500 एचपी ईएमडी इंजन से बेहतर है, परन्तु ईएमडी लोकोमोटिव की यांत्रिक दक्षता एमसीबीजी गवर्नर, परिष्कृत टीएससी, आईजीबीटी आधारित एसी–एसी ट्रैक्शन सिस्टम, हाई स्पीड एसी मोटर्स आदि को अपनाने के कारण बेहतर साबित हुई है। इस लेख में, इंजन टेस्ट बेड पर विभिन्न लोड की दशा में एसएफसी में परिवर्तन का विश्लेषण करने का प्रयास किया गया है। ईटी शॉप में परिवर्तित लोड पर गहनपरीक्षण भारतीय रेलवे के विभिन्न क्षेत्रों में चल रहे लोकोमोटिव के बेहतर प्रदर्शन को सुनिश्चित करता है।

1.0 Introduction

Diesel Locomotive Works (DLW now BLW) is a Production Unit (PU) of Indian Railways have been manufacturing different types of Diesel Electric Locomotives since 1961. As on 31/03/21, 4682 Number of Diesel Electric Locomotives were working in Freight/ Passenger/Shunting service in Indian Railways.

For monitoring & measurement, consumption pattern of HSD oil; Design Wing of BLW and Engine Development Directorate of RDSO / Lucknow have commissioned Test Beds which include Computerized Facility of Data logging & Control. These Test Beds have served the purpose of Effective R&D backup to Zonal Railways &Production units, Improvement in Quality of Product, Measurement & Monitoring of Specific Fuel Consumption (SFC) and Developmental testing for all variants of EMD (2-Stroke) / ALCO Diesel (4-Stroke) engines. In this paper, Effort has been done analyses stage-wise SFC of ALCO & EMD Engine.

1.1 Historical Background

During the initial years, 2600HP Engine of ALCO design were produced by BLW and subsequently upgraded the power up to 3600 HP to fulfill enhanced power requirement for Passenger & Freight Traffic. In 1998, technology transfer from General Motors /USA was affected for production of 4000 HP EMD locomotives to fulfill the requirement of Export & Non-Railway customers.

Since its inception, BLW has produced 9389 locomotives till 31/03/2022. Out of which 5031 No. are 2600/ 3100/3300/3600HP ALCO Locomotive and 2467 No. are 4000/4500/ 5500HP EMD locomotives. Besides, 800+ ALCO/EMD Design Locomotive have been supplied to non-Railway customers (i.e., NTPC /BHEL /NCL /UPPCL& Various Developing Countries), out of which 171 ALCO/EMD Design Locomotives have been exported to Srilanka, Bangladesh, Myanmar, Malaysia, Vietnam, Senegal, Mali, Angola, Mali, Sudan, Mozambique, Tanzania etc.

1.2 Technological Development

The V-type (16 cylinder) WDG-3A&WDG-4 Engine produces different levels of power up to eight different notches on operation of throttle handle. Quantum of Traction Load and Auxiliary load determine power demand of engine. So that, generation of Brake Horsepower (BHP) depends on the requirement of Engine Speed and Load-Torque. The load on engine is decided by field excitation of the main generator which is in turn controlled by variation of excitation system of companion alternator, maneuvered by load control rheostat (LCR). Diesel Engines are equipped with MCBG to obtain better fuel efficiency. MCBG facilitates air/fuel (A:F) ratio as per required load condition and minimizes the unburnt fuel exhausted in atmosphere.

The Governor and Turbosupercharger are key components of Energy conversion in Internal Combustion (IC) Engine. Technological Development in field of Material Science, Welding Technology, Instrumentation Electronics and Integrated Chips, Microprocessor Controlled Electronic Governor has rendered lesser amount of FUEL Consumption for generation of same.

2.0 Concept & Relevance of Specific Fuel Consumption

Indian Railways has practice of measuring SFC, for both type of Engine (freight/Passenger Train) to assess the performance of the engine as well as complete train formation. SFC has been defined as the amount of fuel consumed for one unit of mechanical work. The unit of Engine SFC is gram/ BHP-Hour. In the First Method, the SFC of the engine is measured and calculated by Horsepower output in units of BHP-Hr for a specific quantity of fuel consumption, while the engine is put under load condition during load box test. In the Second method, SFC of Locomotive is calculated by hauling of Train Load (Ton) for a specific distance (in Km). This approach is more practical since Losses incurred in hauling of train are duly accounted for. For locomotives in the shunting service GTKM earnings are generally not recorded by Zonal Railways. As per the Annual Statistics of the year 2000- 2001, the values of SFCs for Freight Service & Passenger Service were reported as: SFC(Goods) = 2.62 Litres/1000 GTKM SFC(Pass) = 4.65 Litres/ 1000 GTKM.

3.0 Literature Review

Some related literatures have been examined and quoted as under:

3.1 Paper on Technologies Adopted in Diesel Locomotive Engines

(Engineering & 2017, n.d.) has compared the two different types of technologies adopted by the Indian Railways during last Six Decades. i.e., Two-stroke Engine manufactured by General Motors Electro-Motive Division (EMD) locomotives and the Four-stroke Engine manufactured by American Locomotive Company (ALCO).

The author has also emphasized the vital Role of diesel locomotives in Transportation Logistics of Indian Railways, who run a sizable number of trains by Diesel Electric Locomotives. The EMD locomotives have been in service for the last two decades.

3.2 Paper on Development of an Electronic Fuel Injection System for 4-stroke Locomotive Diesel

(Sharma et al., 2012) In this paper, an Electronic Fuel Injection system over a 'Mechanical Fuel Injection System along with description of 'Development and Implementation process for retrofitting EFI system in ALCO locomotives. Whereas the conventional system was controlled

Whereas the conventional system was controlled by speed and load, hence resulted in sub-optimal fuel injection at other engine operating points. There are three major parts of the mechanical fuel injection system of the engine: fuel injection pump, high-pressure tubing, and a fuel injection nozzle.

3.3 Paper on comparative Evaluation of Turbo Chargers for HHP Loco

(Gautam & Agarwal, 2013) have discussed on Specific Technical Specifications of 2310 kW Diesel Electric engine. Turbochargers used in this study are a combination of single-stage axial flow turbines and Centrifugal Compressors. The experimental results and findings of the researchers will help in making informed decisions regarding the selection of optimized turbochargers for Alco & EMD Locomotive operating in Indian Railways.

3.4 Paper on 'How to calculate the fuel consumption of a locomotive engine depending on its operating circumstances.

(Rymaniak, 2019) have focused on SFC in Engines of Diesel Electric Locomotive. The SFC is analysed based on certain engine's operating parameters & environmental factors mentioned based on actual field data off-road machines and rail vehicles.

This paper also envisages 'Improvement in Vehicle's efficiency' through the implementation of a start-stop system.

The present method of determining SFC also finds applications in construction works, optimized propulsion system operation by introduction of eco driving rules for train drivers &selection of appropriate operational routes. It is summarized that the SFC calculation in diesel locomotive is based on experimental and computational approaches.

3.5 Paper on Operating a locomotive diesel engine with the best possible specific fuel consumption.

(Popa & Ghei, 2020) has analysed Brake Specific Fuel Consumption (BSFC), the calculation of BSFC and Engine Power-Speed characteristics based on experimental determination and Creation of SFC maps for various power and speed ranges. For the maximum power the optimum SFC is 230 g/kWh at 525 to 675 rpm. The 'Development in the field of Fuel consumption optimization in ALCO&EMD' Diesel Engine for railway applications along with Anticipated benefits of Control Chart/Statistical Analysis in Identified areas for further Research.

4.0 Objective of the Study

The specific fuel consumption (SFC) of Engine plays a vital role in determining the fuel efficiency of Passenger/Freight/Shunting service. SFC values vary with the types of locomotives.

Variations in SFC depend on type of control systems and quality of energy resources viz. Diesel, CNG, Biodiesel, Methanol etc. Improvement in SFC figures of modern engines is the consequence of improvements in engine technology including microprocessor-based fuel injection systems, turbocharging, and fuel combustion efficiency.

By addressing the above-mentioned research gap, this study seeks to provide insights into the fuel efficiency of these Engine types and offer recommendations for optimizing fuel consumption under varying operating conditions. The findings of this study are intended to provide insight for enhancing locomotive performance, reducing fuel costs, and minimizing environmental impacts.

5.0 Engine Testing Procedure

RDSO/Lucknow' that is the nodal agency of Indian Railways regarding Design & Development of energy efficient equipment, engine research laboratory in RDSO/Lucknow has been entrusted with task of 'Prototype Tests' & 'Alternative Test Plan' for Optimised Fuel consumption in Diesel Locomotive under varying Load & Changing Environment during Service. Based on field performance, calculation of SFC of a 4-stroke ALCO engine with a 2-stroke locomotive EMD engine, obtained by following methodology:

Fig 5.1 Test Bed for 16 Cylinder ALCO Engine

Fig 5.2 Test Commander for 3300HP ALCO Engine

Fig 5.3 Test Bed for 16 Cylinder EMD Engine

Fig 5.4 Test Commander for 4500HP EMD Engine

1. Relevant SFC data for both the ALCO engine and EMD engine has been gathered from Engine Test Bed at BLW/Varanasi as per original manufacturer specifications, technical documents of RDSO /Lucknow, National/International research Papers & Transport industry publications.
2. To compare the specific parameters, such as 'engine power output', fuel consumption per hour under test/actual operating conditions by engine model has been defined along with the scope and conditions of the comparison for ensuring accurate and meaningful results.
3. Normalization of the SFC data to a common unit has been done for accurate comparison of ALCO& EMD Engine such as Conversion of the SFC data to a consistent unit such as gram/BHP-hr. Process of normalizing the data is likely to ensure that the test results for both engine types are represented in the same unit and similar test/operating conditions.
4. The operating conditions such as load, speed, ambient temperature, and humidity may significantly impact fuel consumption of engine. Therefore, average SFC data has been considered the actual operating conditions.
5. Basic statistical analysis techniques & graphical tool of Microsoft Excel has been used for analysis of the SFC data under specific parameters such as HP, RPM, fuel schedule, and booster air pressure & charge air pressure of the engine intake system are listed, notch by notch.
6. Consideration has been given to important Factors viz. Notch wise power output, Fuel Consumed per Hour, Speed-torque characteristics, Thermal Efficiency and Mechanical Efficiency, which significantly influence SFC. Other Factors such as emission levels, maintenance requirements and reliability also impact overall engine.

Results of Load Box Test have been generated by Test Commander for analyzing SFC Data of WDG-3&WDG4 Engine. Historical data on fuel consumption suggests that a fuel-efficient ALCO engine's SFC falls between from154-156 Grams/BHP-Hr and 151Gms/BHP-Hr in case of EMD engine.

	ALCO Power Pack 1391 (09-07-22)				HHP Power Pack (xxxx-2021-22)				
Notch	Time	Power Generated	Speed	SFC	Time	Power Generated	Speed	SFC	Fuel Flow (Kg/Hr)
1	600	165	400	234.14	1500	275	260	234.7	47.5
2	600	330	450	203.93	300	632	348	216	103.4
3	600	660	550	187.29	300	1175	486	191	183.2
4	600	990	650	181.14	300	1579	572	175	158.1
5	900	1485	750	170.4	1500	1926	672	170	301.1
6	900	1980	850	159.38	1500	2961	767	167	492.8
7	900	2640	950	151.35	1500	3815	862	159	608.8
8	1800	2750	1050	151.4	1800	4504	960	157	715.1
8	900	2950	1050	152.6	1800	4511	960	158.2	713.8
8	900	3150	1050	153.7	600	4592	960	159.6	728.1
8	3600	3225	1050	154.9	1800	4503	960	158.8	715.2

6.0 Tabulation of SFC Data

The Engine Division of BLW is involved in the assembly and testing of 12 and 16-cylinder ALCO-designed engines and 16-cylinder HHP diesel engines of EMD design. Engine Test Shop (ETS) is equipped with 04 No Engine Test Bed (02 No Each for ALCO &HHP engine). Engine Test Bed has provision of Engine testing with Alternator. Transducers and Gauges are interfaced with Computers and Display &Recording Units in Test Bed. In the study of SFC of ALCO&EMD Locomotive; an attempt has been made to understand Techno-Economic aspect of Energy Efficiency by diving into principles of energy conversion system and measures taken by RDSO/Lucknow & BLW/Varanasi and pertinent environmental issues with diesel electric traction viz. greenhouse gas (GHG) emission. Example: -the quantity of fuel injection varies at different notches to obtain variable power during LOAD BOX Testing. MCBG has yielded reduced fuel consumption in IC Engines. The Complete Combustion of fuel facilitates in zeroing down particulate matter& CO from emitted gases. The functioning of auxiliary power unit (APU) during Idling condition of engine enabled substantial saving of fuel. Logbooks of locomotive playing all over Zonal Railways & History Sheets and maintained by **Diesel Loco Sheds** form basis for Calculation of SFC during **Operation/Service.**

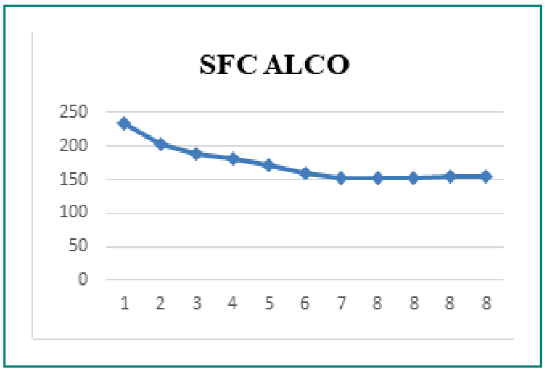
Further Analysis of SFC of ALCO & HHP Engines has been carried out during Manufacturing Process & Train Operation as under: -

As per Engine Directorate/RDSO Report No. TR/ED/2001/137 Oct-2001, SFC figure of 156 gm/bhp-hr has been specified against which 154.32 gm/bhp-hr & 156.24 gm/bhp-hr has been achieved for 3100 HP & 3300 HP ALCO Engine respectively at RDSO Engine Test Bed.

ALCO SFC Improvement (Year Wise:1965-2023) analysis of the Specific Fuel Consumption (SFC) in Gram/BHP-Hr for ALCO (WDG-3A) and EMD(WDG-4); as observed during Testing of Powerpack in Engine Test Shop of BLW/Varanasi Analysis of SFC in this section includes Parameters like power generated, speed, SFC fuel flow for ALCO Power Pack 1391 as well as EMD. Here is a summary & interpretation of the results:

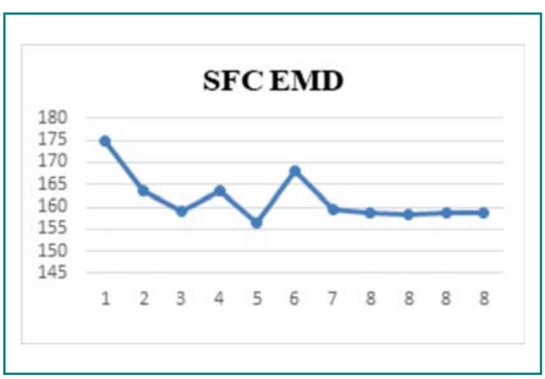
ALCO Power Pack 1391:

The SFC values for ALCO Power Pack 1391 range from 234.14 gm/BHP-Hr (notch 1) to 151.4 gm/BHP-Hr (notch 8). As the engine notch increases, the power and speed also increase, while the SFC decreases with increase in Brake Power Output. At notch 7, the lowest SFC is 151.35 gm/BHP-Hr at 950 RPM for 2640 HP. At Notch 8, the SFC has slight increase 151.4 at 1050 RPM and 154.9 at 3225 HP. Decrease in SFC is nominal with increase in BHP from 3100 HP Onwards.



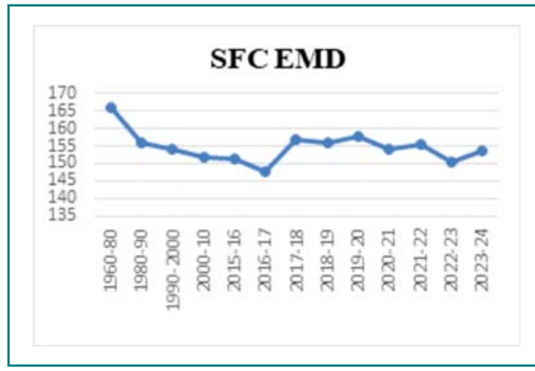
HHP Power Pack:

The SFC of HHP Power Pack is 234.7 gm/BHP-HR at 1st notch and 159.6 gm/BHP-HR at 8th notch. The power and speed increases with increasing notches, while the SFC decreases. The SFC at 8th notch is 158.2 gm/BHP-Hr at 960 RPM & Power Generated is 4503 HP. In the load condition the fuel flow ranges are 103.4 kg/hr (notch 2) to 728.1 kg/hr (notch 8).



7.0 Analysis of SFC (Gm/Bhp-Hr)

Analysis of Engine Test Bed Data of BLW/Varanasi suggest that overall SFC of ALCO Engine is 153.75 gm/bhp-hr at 950 RPM which is almost close to 154.32 gm/bhp-hr for 3100 HP Prototype Engine at RDSO /Lucknow and SFC Figure of 154+/-4 gm/bhp-hr, as specified in ALCO user manual available with Design Wing of BLW/Varanasi. EMD Engine at 8thNotch shows the lowest SFC value of 158.2 gm/BHP-HR at 960 RPM & Generated Power of 4503 HP in comparison to nominal SFC of 158.8 gm/bhp-hr; as specified in EMD User Manual available with Design Wing of BLW/Varanasi.



Environment Conditions play a crucial role in variation of SFC i.e. 154+/-4 gm/bhp-hr,it is varies from 150 gm/bhp-hr to 158 gm/bhp-hr depending upon Test Bed Setup & Environment Conditions. It is also observed that SFC of Engine in Winter is lesser than summer. Max. SFC of 157.8 was during peak Summer of June Month, while Min. SFC of 147.48 gm/bhp-hr was observed in peak Winter of January Month. In the ambient condition, it is also observed that SFC and thermal efficiency of ALCO 251 Engine (4-Stroke) is slightly higher than EMD Engine 710 B (2-Stroke).

8.0 Discussion of SFC

(ENGINE: ALCO& EMD Design)

Results of SFC during operation of ENGINE has been analysed in previous section based on available Experimental/Field Test Data. Overall Comparison of SFC of ALCO & EMD may be summarized as under: -

1) Both ALCO &EMD power packs demonstrate a similar trend with increasing notches, where higher power and speed are achieved with lower SFC values till 7th notch.

2) The HHP Power Pack generally has lower SFC values compared to the ALCO Power Pack at 8th notch.

3) Fuel flow is generally higher for the EMD Power Pack compared to the ALCO Power Pack due to generation of Higher HP. Results of Engine Test Bed of RDSO/Lucknow have demonstrated almost similar Results. Although ALCO Locomotive has a 4-Stroke Engine, it's SFC(Litre/GTKM) is inferior to EMD Locomotive because of older DC Motor technology & Electromagnetic Contactor Based Propulsion System. The latest IGBT Technology has rendered better Fuel Efficiency to 4-Stroke Engine of General Electric Locomotive in comparison to EMD Loco. The SFC of Diesel Electric Locomotive has also demonstrated consistently downward trend due to Technological Upgradation in components of ALCO &EMD Locomotive viz. Turbo Super Charger, Electronic Governor, three phase propulsion system, V/f control of AC Motors. REMMLOT and APU during IDLE period has also been one of the most reason.

Detailed ANALYSIS of Duty Cycle of Loco has revealed that Freight & Passenger ALCO& EMD Locomotive are operating at 8th notch most of the Time (Excluding Period of IDLE/Stable in Yard).Since most of the time Loco has running at 8th notch; so, it is desirable to have better SFC at Higher Notches to haul Load Train (4700 Ton.). Several Experimental Results Engine Test Bed at RDSO/Lucknow have established that SFC of EMD Engine (Litre/GTKM) has been 4-5 % less than that of ALCO Engine (Litre/GTKM) at 8th notch (Full Load) because of better Traction System.

9.0 Conclusion

Energy Engineers are aware that Efficient fuel utilization is crucial for the optimal operation of Engines and cost-effectiveness in Train Operation. Under varying Environmental Condition & Dusty/Dirty Atmosphere, Field Performance of ALCO/EMD Engine decreases during Freight /Passenger /Shunting Service; consequently, Fuel Consumption of Locomotive per KM Service also increases.

Engines manufactured by BLW are maintained & serviced by Diesel Loco Sheds of respective Zonal Railways for uninterrupted Train Operation. Improvement in SFC of ALCO & EMD Engines over the years have not only led to saving in cost of Scarce Oil Resources but also Reduction in Green House Gas Emission have been consistently achieved during Train Operation.

The parameter of SFC conveys more meaningful behavior of 2-Stroke/4-Stroke IC Engine at different Load under variable Environment conditions. Measurement of SFC of Fuel & Monitoring of Lubricant's consumption is also intended to improve Reliability of Engine during Service.

Interpretation of Statistical Data such as average value of SFC suggest variation in the range of 4-4.5 litres /1000GTKM for passenger train and 2.25 to 2.75litres/ 1000GTKM for Goods/Freight train.

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Fabrication and Applications of Fiber Bragg Grating

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Abstract : **A fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by creating a periodic variation in the refractive index of the fiber core, which generates a wavelength-specific dielectric mirror.**

सारांश : फाइबर ब्रैग ग्राटिंग (FBG) एक प्रकार का वितरित ब्रैग परावर्तक है जो ऑप्टिकल फाइबर के एक छोटे खंड में निर्मित होता है जो प्रकाश की विशेष तरंग दैर्ध्य को दर्शाता है और अन्य सभी को प्रसारित करता है। यह फाइबर कोर के अपवर्तक सूचकांक में आवधिक भिन्नता पैदा करके प्राप्त किया जाता है, जो तरंग दैर्ध्य–विशिष्ट ढांकता हुआ दर्पण उत्पन्न करता है।

Introduction

Fiber Bragg grating based WILD system developed by RDSO with collaboration to Start-up Company M/s Lab to Market Innovation Pvt Ltd and Indian Institute of Science Bangalore. Two number field level prototypes after successful trial, has been installed at LC Gate No. of 130 and LC Gate No. 15 of Bangalore Division of South Western Railway. After successfully commissioning it has been handed over to Bangalore Division for its operation and maintenance.

FBG sensors used as shown in Fig-2, offer most popular in large-scale applications, as it allows for both static and dynamic monitoring of strain and temperature.

Fiber Bragg Grating – FBG

The Fiber Bragg grating is a great emerging technology in optical applications because it has various unique properties. Fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length which is formed by exposure of the core to an intense optical interference pattern as shown in the figure below.

Fig:1. FBG Sensor

The modulation of the refractive index causes an FBG to act like a mirror that reflects certain wavelengths and transmits others. Normal optical fiber are uniform along their lengths. In a simple fiber Bragg grating, the refractive index of the fiber core varies periodically along the length of the fiber.

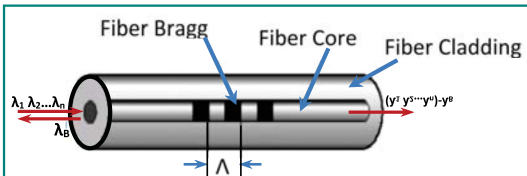


Fig:2. Schematic of a Fiber Bragg Grating

Reflection & Transmission of FBG Light:

As shown in the above figure, the refractive index of the fiber core is modulated with a period of Λ. When a light with a broad spectrum is launched into one end of fiber containing a fiber Bragg grating, the part of the light with wavelength matching the Bragg grating wavelength will be reflected back to the input end, with the rest of the light passing through to the other end. This reflection phenomena is explained in the following figure.

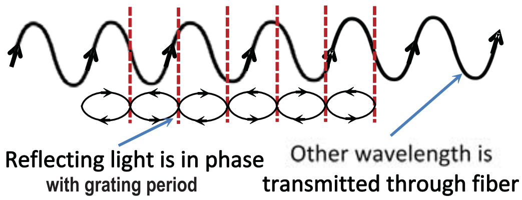


Fig:3. Light Reflection and Transmission in a Fiber Bragg Grating

When the grating period is about half the input wavelength of light, all the reflected light signals merge comprehensibly to one large reflection at a specific channel. This is known as the Bragg condition. From the conservation of momentum the Bragg grating condition hold as shown in following equation.

$$\frac{2(2\pi n_{eff})}{\lambda_B} = 2\pi/\Lambda$$

where n_{eff} is the effective refractive index of the fiber core, and λ_B is the wavelength of the reflected light by the Bragg grating.

Therefore, the Bragg grating wavelength λ_B can be expressed as

$\lambda_B = 2.\Lambda.n_{eff}$

It shows that bragg grating wavelength is the function of the effective index and the period of the grating.

Any change of fiber properties, such as strain, temperature or polarization which varies the model index will change the bragg wavelength.

The development of permanent grating in optical fiber was first introduced by Hill.

Fiber Bragg Grating Structure:

The structure of the FBG can vary via the refractive index, or the grating period. The grating period can be uniform or graded, and either localized or distributed in a superstructure.

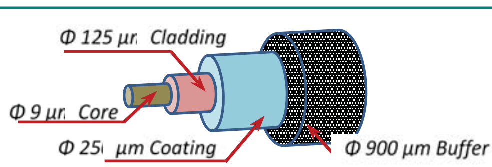


Fig:4. Fiber core structure

There are six common structures for Fiber Bragg Gratings being used.

1. Uniform positive index change
2. Gaussian apodized
3. Raised-cosine apodized
4. Chirped
5. Discrete phase shift
6. Superstructure

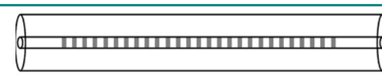


Fig: 5.1 Uniform Fiber Bragg

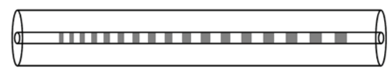


Fig: 5.2 Chirped Fiber Bragg

Fig: 5.3 Tilted Fiber Bragg Grating

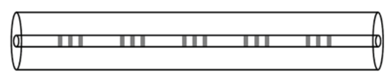


Fig: 5.4 Superstructure Fiber Bragg

Fiber Bragg Grating Sensors:

For measuring mechanical and physical phenomena electrical sensors have been used. These sensors have intrinsic borders like susceptibility to interference and transmission loss that make their usage challenging in many applications. Optical fiber sensing is the best solution to these challenges, using light as compare to electricity and standard optical fiber instead of copper wire. The several innovations over the last two decades in the field of fiber-optic communication & optoelectronics taken place. The fiber-optic sensor works by modulating one or more properties of a propagating light wave, intensity, including phase, polarization and frequency in response to the environmental parameters to be measured. Intrinsic optical sensors utilize the optical fiber itself as the sensing element. The most commonly used optical sensors are the fiber Bragg grating that reflects a wavelength of light in response to variations in strain and temperature. Application based FBG sensors are constructed by special technique. These sensors are constructed by using a phase mask or holographic interference. When a broad light beam is send to FBG, reflections from each segment of alternating refractive index interfere constructively only for a definite wavelength of light, known as Bragg wavelength, described in equation. This effectively causes the FBG to reflect a specific frequency of light while transmitting all others. As well as being sensitive to strain, the Bragg wavelength λ_B is also sensitive to temperature. This means that fiber Bragg gratings can be used as sensing elements in optical fiber sensors.

In a FBG sensor, the measure and causes a shift in the Bragg wavelength, $\Delta\lambda_B$. The relative shift in the Bragg wavelength, $\Delta\lambda_B / \lambda_B$, due to an applied strain (ε) and a change in temperature (ΔT) is approximately given as below.

$$\frac{(\Delta\lambda_B)}{\lambda_B} = C_S.\varepsilon + C_T.\Delta T$$

Fiber Bragg gratings can then be used as direct sensing elements for strain and temperature.

Formation of Fiber Bragg Grating:

The two overlapping UV light beams generates a periodic interference pattern as shown below has equivalent periodic index grating. The UV radiation is split into two equal-intensity beams and then recombined to produce an interfer- ence pattern within the core, normal to the fiber axis. The intensity of the pattern is increased by focusing the beams on the fiber with a pair of cylindrical lenses. It generates the Hill gratings the wavelength of the blue argon laser lineg.

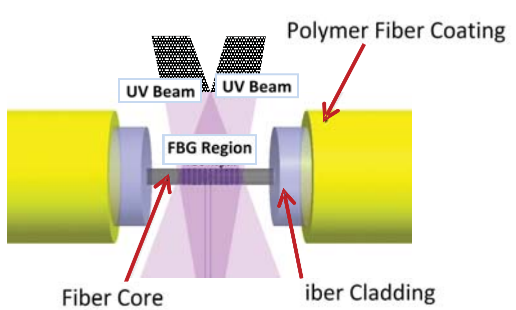


Fig:6 Fiber Bragg Grating Device

There are three main formation technique of the Fiber Bragg grating as detail given below.

I. The Interferometry Technique:

This technique is based on the interferometer which splits the incoming laser beam into two beams and then recombines them to form an interference pattern. The interference pattern induces a refractive index modulation in the fiber core with the same spatial periodicity as the interference pattern.

Obtaining of very high refractive index changes is depended on the high contrast and stability of the interference pattern. The spatial period Λ is related with the writing wavelength on the basis of equation:

$$\Lambda = \frac{\lambda_{UV}}{2.\sin(\theta/2)}$$

Where λ_{UV} is wavelength of the basic laser beam, θ is the intersecting angle between two writings beams. By changing the intersecting angle θ between the two writing beams, having a wavelength equal to λ_{UV}, it is possible to write Bragg grating for almost any wavelength. This method offers a good flexibility for producing gratings of different lengths.

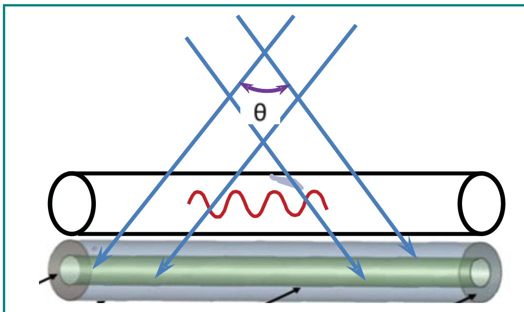


Fig:7 Interference fringes induced by two interfering UV beams

II. The Point by Point technique:

In this technique the pulse excimer laser is used to writing the changes of refractive index to the core of the optical fiber. The change of refraction index is induced along the core of the fiber a step at a time. A single pulse of the UV light from an excimer laser passes through a mask to the core of the fiber containing a slit and thus the refractive index of the corresponding core section increases locally. The fiber is then translated through a distance corresponding to the grating pitch in parallel direction to the fiber axis and the process is repeated to form the grating structure in the fibers core.

Advantages: This technique is the possibilities to locally modify the Λ and to realize very long gratings.

Disadvantage: It is the shift in the axis core direction. This shift must be very accurate.

III. The Phase Mask Technique:

This is the widely used technique for reproducible Bragg gratings fabrication. The phase mask is a diffractive optical element that spatially modulates the UV laser writing beam. The phase mask can be formed by holographically or by electron-beam lithography in a high quality fused silica, transparent for the UV writing beam. The advantage of holographic formed phase mask is no stitching error. The stitching error is normally present in the electron-beam formed phase mask. The profile of the periodic grating corrugation is chosen to suppress the zero order diffracted beam to a very small percentage of the transmitted power (less than 5%). On the other side, the diffracted plus and minus first orders are maximized, each containing typically more than 35% of the transmitted power. A near-field fringe pattern is produced by the interference of the plus and minus first-order diffracted beams. This pattern photo induces a refractive index modulation in the core of the photosensitive optical fiber placed in close proximity, immediately behind the mask. At negligible zero order contribution, for fibers aligned parallel to the phase mask, the period of the fringes is one-half of the phase mask period, Λpm.

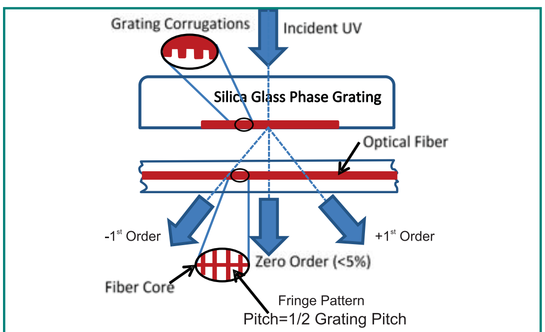


Fig:8 Phase mask writing technique

Advantage: The simplicity of the phase mask writing technique provides a robust and inherently stable method for producing fiber Bragg gratings. Since the fiber is usually close to the mask, the sensitivity to mechanical vibrations and stability problems are minimized.

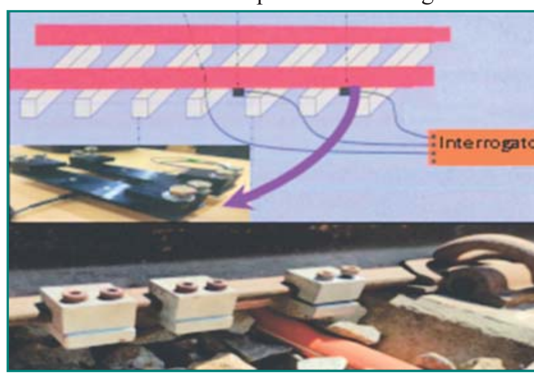
Disadvantage: The phase mask technique is the need of a mask for each desired Bragg wavelength.

Advantages of FBG sensors

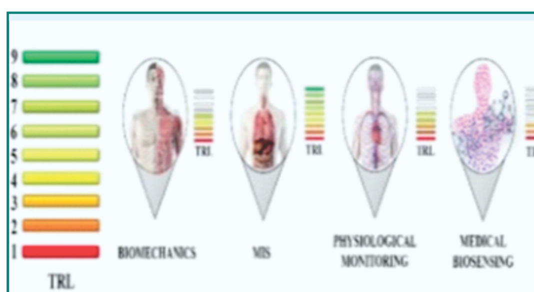
- Insensitive to electromagnetic interference (EMI)
- Passive sensor element, Chemically inert
- High bandwidth
- Large array of sensors can be placed on the same fiber
- Offers multiplexing of large number of sensors
- Small size, light weight, hence non-obtrusive
- Remote location and embedded sensing
- As a point sensor, can be used to sense normally inaccessible regions without perturbation of transmitted signals
- Eliminates bulk electronics for signal conditioning and cabling
- High linearity, sensitivity, accuracy and resolution

Fiber Bragg Grating Applications

- **FBG Sensors for condition monitoring of the railway assets :** FBG system which can monitor health of rolling stock as it passes through it on real-time basis can help in timely detection of defect for further attention and repairs to the rolling stock.

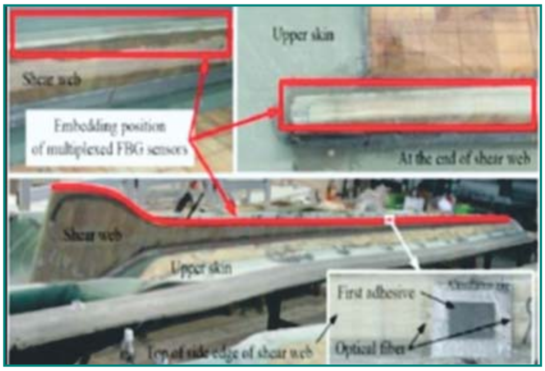


- **FBG sensors for the Medical science :** Its broad application in medical science field due to their unique properties such as small size, biocompatibility, immunity to electromagnetic interferences, high sensitivity and multiplexing capability.

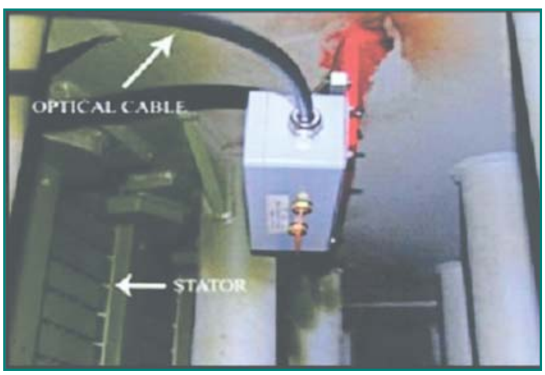


- **FBG sensors for Aerospace Industry:** For various applications in the field of aerospace engineering, such as pressure sensing, ground-based

- aerodynamic test facilities, shock pressure sensing, spacecraft monitoring and structural health monitoring of aircraft composites.



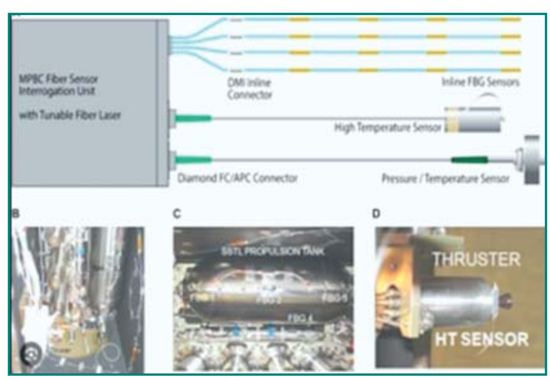
- **FBG sensors for the electric power:** FBG temperature sensor array for monitoring temperature variation of the hydro-electric generators, which is normally a consequence of the current and must be kept under close observation because rises above 1000C may accelerate the aging of insulating materials and conductors.



- **Monitoring of power transmission :** Lines in-service time, the variability in structural, thermal and environmental loads, the state of foundations (displacement and degradation), the corrosion of supporting structures and lack of technical documentation are essential factors to be monitored real time using FBG sensors.

- **FBG Sensors for Mines:** The FBG signals received and analyzed to determine the location and energy level of the source of the micro-seismic event warning.

- **FBG sensors for defence :** FBG sensors for structural health monitoring (SHM) in aerospace fiber reinforced polymer (FRP) Structures. It's an innovative method to interpret FBG signals for identifying damage inside the structure.



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Effect of Adhesion Promoting Primer on Stainless Steel Side Wall of Railway Coaches


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ICF-Chennai

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C&M Supdt.
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Abstract : Adhesion & Compatibility of paint coatings is a very crucial factor in determining the Durability of Paints. This paper aims to evaluate the adhesion strength of APP on bare metal and the compatibility / adhesion strength between Etch primer & Adhesion Promoting Primer.

In this study, we are going to deal with Etch primer & Adhesion Promoting Primer in detail and the test methods to evaluate the Compatibility / Adhesion strength of both Etch Primer and Adhesion Promoting Primer. This study also reveals the advantages and disadvantages of Etch Primer & Adhesion Promoting Primer and their application in Indian Railways. This paper study reveals also the adhesion promoting primer is having better adhesion with bare metal than with other paints.

सारांश : पेंट कोटिंग्स का आसंजन और अनुकूलता पेंट्स की स्थायित्व निर्धारित करने में एक बहुत ही महत्वपूर्ण कारक है। इस पेपर का उद्देश्य नंगे धातु पर एपीपी की आसंजन शक्ति और ईच प्राइमर और आसंजन प्रमोटिंग प्राइमर के बीच अनुकूलता/आसंजन शक्ति का मूल्यांकन करना है।

इस अध्ययन में, हम Etch प्राइमर और आसंजन प्रमोटिंग प्राइमर के बारे में विस्तार से चर्चा करेंगे और Etch प्राइमर और आसंजन प्रमोटिंग प्राइमर दोनों की अनुकूलता/आसंजन शक्ति का मूल्यांकन करने के लिए परीक्षण विधियों पर चर्चा करेंगे। इस अध्ययन से एच प्राइमर और आसंजन प्रमोटिंग प्राइमर के फायदे और नुकसान और भारतीय रेलवे में उनके अनुप्रयोग का भी पता चलता है। इस पेपर अध्ययन से यह भी पता चलता है कि आसंजन को बढ़ावा देने वाले प्राइमर में अन्य पेंट की तुलना में नंगे धातु के साथ बेहतर आसंजन होता है।

Introduction:

Both Etch Primer and Adhesion Promoting Primer are exclusively applied on bare metal for the preparation of the surface for further coatings. Hence, it becomes an interesting subject to study the application of both the primers is a needed one or not and their advantages and disadvantages and also the adhesion strength in between them.

Keywords—APP- Adhesion Promoting primer

µm - Microns

SS-Stainless steel

Psi - Pounds per square inch

What are Etch Primer:

Etch primers also called as Pre treatment primers are single / dual pack metal primers with a combination of resins to maximize the adhesion to various metal surfaces on which they are used. A low level of phosphoric acid is present in these primers to etch the metal surface and improve adhesion. The coatings also contain zinc phosphate anti corrosion pigment for steel surfaces.

When should they be used?

Etch primers are used on surfaces that cannot be prepared by abrasive blast cleaning. Surfaces that can be prepared by abrasive blast cleaning, would be better served by a conventional two pack Epoxy primer as they provide better long term corrosion protection than Etch primers.

Advantages:

1. Rapid cure of less than 1 hour provides strong base for top coats
2. Provides good adhesion over variety of different metals than other metal primers
3. Minimal Surface preparation
4. Some degree of corrosion protection

Disadvantages:

1. Not applicable in coastal environment
2. Higher than recommended film thickness (>25µm) causes delamination.

In Indian Railways:

In Railways Etch primer to ICF/MD/Spec.231 (ICF Specification) is recommended for application on the side wall Exterior of Railway coaches. It is a widely used eco friendly modified water based paint.

Adhesion Promoting Primer:

As the name implies Adhesion Promoting Primers improves the adhesion between substrate and coatings by creating an interface for additional covalent bonds. This increases the adhesion and the bond between the substrate and coatings, thereby increasing the strength and the durability of the coatings.

This two pack primer contains acrylic resin, Epoxy ester resin along with Pigments.

When should they be used?

The two pack Adhesion Promoting Primers is intended to be used as first coat on bare metal to provide etching and adhesion to Stainless steel and also works on Corten Steel substrate for interior and exterior application.

They are applied directly on steel surfaces and eliminates Garnet blasting from the operation.

It provides good adhesion on the substrate and good compatibility with subsequent coats.

It is specially used on surfaces where extensive corrosion protection is required.

Advantages:

1. Rapid cure of less than 1 hour provides strong base for top coats
2. Provides Excellent adhesion over variety of different metals. (Pull off Strength 850 Psi)
3. No Surface preparation
4. Excellent degree of corrosion protection upto 500 hours
5. Superior Humidity resistance upto 1000 hours.
6. Good Impact resistance
7. Good Fire resistance

Disadvantage:

1. Expensive than the conventional epoxy primers.

In Indian Railways:

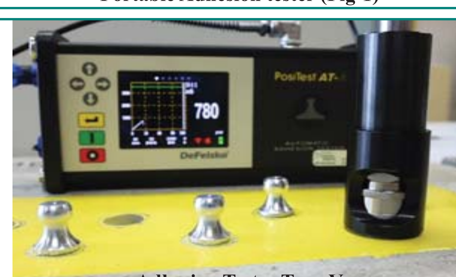
In Railways Adhesion Promoting Primers to MDTS 48279 (RCF Specification) is recommended for application on the side wall Exterior of Railway coaches. This superior primer rapidly replacing the commonly used Epoxy zinc phosphate primers in various industries.

Compatibility Study of Etch Primer and Adhesion Promoting Primer (app) Experiment – Pull off Strength

SS test panels were prepared with Etch primer on bare metal, APP on bare metal and Etch primer + APP on bare metal and tested for Pull off strength as per ASTM D 4541-17 (Fig-1).

This test method covers a procedure for evaluating the pull-off strength of a coating system from metal substrates. This test method maximizes tensile stress as compared to the shear stress applied by other methods. This test is performed by securing a loading fixture dolly of 20 mm dia normal to the surface of the coating with a glue. After the glue is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture at a rate of 150 psi /sec or less and monitored until the loading fixture is detached. The force at which loading fixture detaches from the substrate is considered as the pull off strength of the coating.

Portable Adhesion tester (Fig-1)



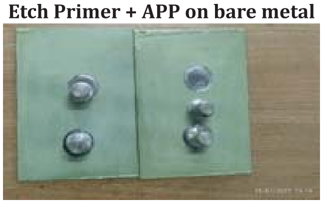
Adhesion Tester Type V

Loading Fixtures of 20 mm dia.

(Fig-2) Pull off strength test

Etch Primer on Bare metal

Etch Primer + APP on bare metal

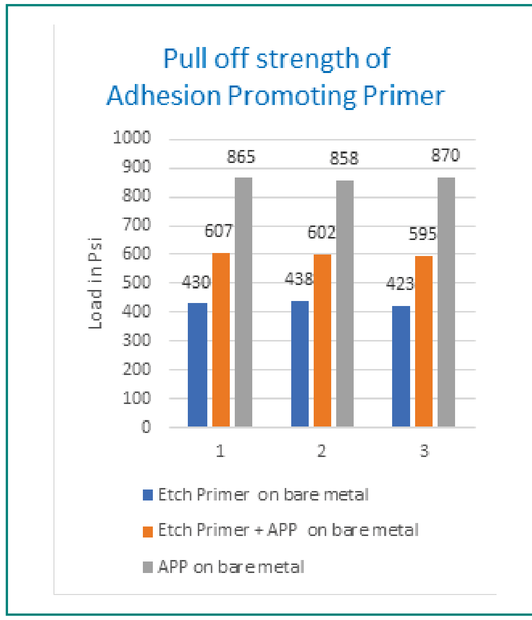


APP on bare metal

Table-1 Pull off strength test

S.No.	Etch Primer on bare metal	Etch Primer + APP on bare metal	APP on bare metal Requirement-850 Psi (min)
1.	430	607	865
2.	438	602	858
3.	423	595	870

Graphical representation of the Pull off Strength



Following is the observation made:

Adhesion Strength of APP was lowered when it is applied over Etch primer in comparison with the Adhesion Strength of APP on bare metal.

Conclusion:

From the experimental analysis,

1. Adhesion Promoting primer is far superior in providing the Adhesion strength than Etch Primer.
2. Adhesion strength of Adhesion Promoting primer is lowered when it is applied over and above the Etch primer.

References:

1. ICF/MD/Spec.231
2. MDTS 48279 Rev.03
3. ASTM D 1002-2010
4. ASTM D 4541-17

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Articles are invited from the serving and retired Railway personnel of the Zonal Railways, Railway Institutes and Production Units for publication in Indian Railway Technical Bulletin (IRTB) on:

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