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TRACTION ROLLING STOCK



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भारतीय रेल विद्युत विभाग की पूर्ण रूपसे एकमात्र तकनीकी पत्रिका
(त्रैमासिक)

(रेलवे के विद्युत विभाग कार्यालय के लिए निशुःल्क वितरण हेतु)
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लेख संपर्क एवं पत्राचार हेतु पता

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संरक्षक
श्री शैलेंद्र त्रिपाठी
निदेशक

कार्यकारी संपादक
श्री ए. ए. फडके
व. प्राध्यापक (जी.)

सह-संपादक
श्री प्र. कु. बंद्योपाध्याय
ग्रंथालय

संपादकीय

इस अंक के पहले लेख में WAG 9 विद्युत इंजिन की विश्वसनीयता पर विशेष प्रकाश डाला गया है। इसमें इलेक्ट्रिकल इक्यूपमेंट कार्डस्, ऑग्जिलरी, सेन्सार्स आदि के बारे में चर्चा की गई है।

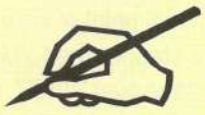
दूसरे लेख में Commutator Fitment on TAO-659 Traction Motor के संबंध में जानकारी दी गई है।

तीसरे लेख में टी एम डब्ल्यू नासिक में आर्मेचर रिवाईडिंग की विभिन्न परीक्षण स्टेजेस संबंधी जानकारी प्रस्तुत किया गया है।

चतुर्थ लेख में इलेक्ट्रिक मशीन एवं ड्राइव्ज की क्षमता के बारे में विदेशी लेखक द्वारा भेजे गये लेख को प्रस्तुत किया गया है।

आशा है यह अंक आपको अवश्य पसंद आयेगा, फिर भी इरीन जर्नल की गुणवत्ता में अधिक सुधार लाने के लिए सुझाव भेजें।

आपके पत्र की प्रतीक्षा में



- संपादक

RELIABILITY ISSUES OF WAG 9

By Pradeep Rathore/SCR
(Based on Project Report)

Introduction

In the year 1996, 22 WAG 9 locos were imported from ABB, Switzerland. On November 1998, CLW started producing WAG 9 with indigenous components. The first one, 'Navyug', was flagged off on Nov 14.

The primary motivation behind the induction of the 3-phase technology for freight locos was to achieve heavy throughout and faster sectional clearance. This was where these heavy haul and speedier WAG-9 locos had to play a significant role. As it was claimed that a single unit can start a 4700t load (58 BOXN wagons) on a gradient of 1: 180, a great improvement over the WAG-5/WAG-7 locos, that were restricted to haul such loads in sections of gradients 1:200or less.

WAG 9 vis-à-vis WAG 7

Attributes	WAG 7	WAG 9
Axle load	20.5t	20.5t(Without ballast)
MPS	100 kmph	100kmph
Starting TE	402KN	460KN
Continuous TE	235KN	325KN
Breaking	Pneumatic & Dynamic	Pneumatic & Regenerative
Adhesion	34.5%	35%
Cost	Rs.4.8 Cr	Rs. 12.77 Cr

From the operational point of view; if ruling gradient in the section is 100 or steeper then WAG 9 does not offer any additional advantage over WAG7, as multiple units have to offer for all the enhanced loads. Further isolation of anti spin brake also adversely affects the adhesion of loco.

The table below gives an idea of haulage capacity of WAG 9 & WAG 7:-

Type of Locomotive	1 in 100	1 in 150	1 in 200
WAG 7	*Can negotiate 0.5 km at 20 kmph with 41 BCN (CC+ 6+2)365t ** Can negotiate 0.5 km at 30kmph with 59 BOXN (CC+ 10) 5400t	*Can negotiate 3.5 km at 20 kmph with 48 BTPN,4000t. ** Can negotiate 1 km at 30 kmph with 59 BOXN (CC+ 10) 5400t ***Loco can start and haul 40 BCN (CC+6+2),3571t	*Can negotiate 2.5 km stretch at 20 kmph with 59 BOXN (CC+ 10) 5400t **Loco can start and haul 58 BONX,4700t
WAG 9	*Can negotiate 0.5 km at 20 kmph with 41 BCN (CC+ 6+2) 3757t ** Can negotiate 0.5 km at 30 kmph with 59 BOXN (CC+ 10) 5400t	*Loco can start and haul 48 BTPN, 4000t. **Can negotiate 0.5 km stretch at 30 kmph with 59 BOXN (CC+ 10)5400t	*Can negotiate 4.0 km stretch at 20 kmph with 59 BOXN(CC+ 10) 5400t **Loco can start and haul 58 BONX (CC +6) 5062t

Scale of failures

WAG 9 locomotives have been operating on the Indian Railways since 1996. These locos have been tipped as future of electric locomotion and a necessity for freight traffic to cater the buoyed Indian economy. By now 180 WAG 9 locomotives are plying on Indian Railways.

But extent of failure and reliability of these locomotives is far from satisfactory and unfortunately even after 10 years of operation there is no sign of improvement in the online performance of these locomotives. For example in Electric loco shed Lalaguda, for average holding of 18.5 there were 317 failures in FY 07-08.

Electrical /Electronics	242
Pneumatic	49
Mechanical	26
Total	317

Similar is the scenario of Ajni and Gomoh, where mechanical and traction motor failure are on higher side due to older locos.

As mentioned above from operation point of view WAG 9 does not offer any substantial advantage over WAG 7 locomotive. Regenerative breaking and faster clearing of section are other two advantages which are overshadowed by poor reliability.

In view of the above it has become imperative that targeted efforts should be made to reduce the failure of WAG 9 locomotive, otherwise it would be very difficult to justify the necessity of this loco when WAG 7 is around.

WAG 9 loco has more number of components than conventional locomotive; therefore reliability of each and every component becomes more important. Most of these components are electronic devices and various types of transducers which are relatively new for us therefore design, quality of material, manufacturing, maintenance and operation are critical for on-line performance of the locomotive.

Some of the areas require intervention at software level and design is also no independent of software, so quality of material, manufacturing & operation should be the thrust areas.

Major Areas of Concern

1. Electronic Cards

Electronic cards are the biggest contributor to loco failures. Situation becomes further worse then problem is intermittent in nature. There were 65 failures of electronic cards at electric loco shed Lalaguda in FY 07-08. Major contributor was Gate Unite with 21 cases. A cursory look gives the insight that some of the cards are failing more than others. Same is the case with other loco sheds but type may vary. Further failures of cards of particular batch/series are high.

Inadequate cooling appears to be one of the reasons of cards failure. Single-phase machine room blower and ineffective body filter are two important factors contributing to it. Body filter and scavenger blower are not able to prevent fine dust particle especially coal dust from entering in to loco. This fine dust gets deposited on the heat sinks and electronic components and hampers the cooling.

Machine room blower works on the single phase 415 V supply directly fed from auxiliary winding of main transformer. This motor is a 3-phase induction motor, working on single phase supply by doing some external connection to connect capacitors. In order to improve the cooling of electronic components MR blowers can be made to work on three phase 415 V supply from the auxiliary converters. There is enough margin available to feed two MR blower and simple changes in control circuit will enable MR blower to run on single phase AC in cooling mode and on three phase supply in driving mode. Some changes will be required at software level to take care of change over in case of isolation of one BUR. Further poor performance of filters should be taken up with supplier for carrying out the remedial action.

There are several cases when TOT suppliers are returning the failed cards with no defect found, but these cards again give same problem in locomotives, which is also causing transient problems.

Cable screen shielding is a major area of concern; there are a few cables in the locomotive which are not properly shielded. In order to tackle this problem cable harnessing in manufacturing has to be improved. Further double earthing of vehicle electronics, main converter electronics and BUR electronics may be tried to reduce interference.

Further more TOT partner should be asked to investigate the cases where same card is failing again and again to take corrective action on design or software level.

Handling of cards in sheds and workshop during maintenance and troubleshooting should be improved by use of proper anti electrostatic gears and testing equipments.

2. GTO & Associated Components

There are many failures of main converter valve sets and inverter modules of auxiliary converter and components of its snubber circuit 21 such failure occurred in electric loco shed Lalaguda in FY 07-08.

Most of these failures are associated with flashing of power cables, bearing seizure of traction motors, electrical failure of traction motor, failure of auxiliaries and failure of oil pumps.

This is not surprising as large dv/dt that accompanies inductive turn off can not be tolerated by GTO. Therefore a suitably designed snubber circuit must be used across the GTO. Since most of the failure are associated with handling of inductive load, TOT partners should be asked to look into the design of snubber circuit.

Rapid deterioration of converter oil BDV is also a major cause of concern. In 45 days oil BDV is falling to 20 KV and below against the minimum prescribed 30kV. An apparent cause of rapid deterioration is small conservator of converter, which is causing more breathing than usual. Low BDV might also contribute to GTO failures. A bigger conservator can overcome this problem.

3. Bogie and its parts

Failures of bogies and its parts are also a major cause of concern. Little and no knowledge of other sheds and trip sheds further aggravating the situation.

Following are the main problems of bogie and its parts :

- Breakages of traction link near to flange from welded portion.
- Breakages of aclathan ring housing near to flange from welding portion.
- Perishing of aclathan ring well before prescribed service life.
- Breakage and loosening of traction link bolts.
- Failure of dampers.
- Breakage of springs.
- Seizure of axle box bearing.
- Fast reduction of vertical clearances.

The fitment of traction link housing and traction link is such that on curves there would always be stress on the flange joint and if bolts are tight there are fair chances of breakage of either traction link or housing from welded portion. It is also the reason breakage and loosening of traction link bolts. Almost rigid joint between traction link and housing may be modified to spheriblck type of arrangement. The rubber in spheriblock will absorb the force on curves to a great extent.

Electric loco shed of Gomoh and Ajni have been facing this problem of perishing of aclathan ring well before prescribed service life. After 2-3 years of service aclathan rings are losing its properties and housing. As per maintenance manual aclathan ring was to be replaced after 54 months. Due to acute shortage of material a number of locomotives are running with perished aclathan rings.

Each WAG9 locomotive bogie is having 20 dampers and even failure of a single damper causing heavy oscillation of the loco and leading to loco failure. A simple analysis indicates that is a material related problem, as failures are exclusively of indigenous make dampers.

Breakages of springs and problem of vertical clearance is also a material related problem, as failures are again exclusively of indigenous make material only.

Genesis of axle box bearing problem lies in the delayed decision making about :

- ✓ Type of bearing to be used.
- ✓ Type of axle box housing to be used.
- ✓ Whether regreasing is necessary.
- ✓ Frequency of regreasing.

Presently in most of the locomotives of Ajani and Lalaguda sealed bearing are available in the housings, which are having provision of greasing. Recently a decision has been taken to regrease these bearing after 18 months by removing loose lip.

4. Traction Motors

No schedule maintenance of three-phase traction motor is a positive feature. But failure of these motors is a major factor responsible for poor reliability. Three phase traction motors are plagued by both electrical and

mechanical failure and impossibility of isolation of individual motors leading to stalling and on-line failure of locomotive.

Opening of rotor bar and consequent damage of stator has already been discussed time and again and so many corrective modifications have been implemented in the motor. However this problem is still continuing especially in old locomotives of Gomoh and Ajni.

Owing to inherent characteristic of three phase traction motor, frequent start and stop with heavy load is detrimental for motor as motor operates on positive slop of the characteristic curve and draws heavy current. But frequent start and stop is the requirement of freight traffic on Indian Railways and we have to live with it. However to improve the performance of motor other problems like; breakage of pinion, failure of speed and temperature and speed sensor, bearing seisure and rotation of inner labyrinth in end shield should have to be contained.

There is an urgent need of developing a few good sources of gears and pinions. KPL, the only supplier is not able to fulfill requirement of Indian railways. Sheds have been facing acute shortage of pinions of all types of the locos. Non-availability of pinions forcing the sheds to allow pinions with high BTL and even chipped of pinions. The wear rate of WAG 9 pinion is very high and these are to be changed every third year. Therefore the availability of pinions is very critical to maintain availability of the loco.

End shield and its components should be procured only from the suppliers who are required machinery to manufacture these components with great precision.

Failure of speed and temperature sensor of traction motor is very high and constitutes 40% of total traction motor failure. Performance of sensors is a matter of great concern in WAG 9 loco is discussed in detail later.

4. Auxiliary Motors

Rampant failures of auxiliary motors are an important reason of the poor performance of the loco and it is also causing stabling of the locomotives in the sheds due to non-availability of spares, because to this scale of failure it is nearly impossible to plan and procure the material.

For an average holding of 18.5, 30 (num.)auxiliaries failed in FY 07-08 and in first quarter of 08-09 for an average holding of 46,37 (num.) failures took place. These figures give the idea of enormity of the problem.

An analysis of data gives following probable reason of auxiliary motor failures:

- Poor quality of motors.
- Malfunctioning of MCBs.
- Failure of earth fault relay.
- Some known problems have not been taken care of.

Make wise failure data indicates that FRPCPY of motors of some suppliers is very high. For example failure of SHIL make motor is very high. Similarily failures of oil cooling blower motors are exclusively of Indigenous make. There is an urgent need of quality of auxiliary motors.

Malfunctioning of ABB make MCBs is one of the reasons of failure of auxiliary motors. There were numerous cases when MCBs failed to open and continued to feed 2 phases to motor and led to failure to motor due to single phasing. Some MCBs are getting reset even when all three phases are not having continuity. Indian Railways procure these MCBs through some India based traders. Therefore this matter should be taken up with the manufacturer at appropriate level.

There were 14 failures of earth fault relay itself in one year. In some of the cases where there was an intermittent earth fault in auxiliary circuit cables earth fault relay failed to pick up and caused failure of motor due to voltage unbalance/single phasing. In order to avoid such cases testing of earth fault relay should be made part of the pretesting before every schedule.

There are some known problems like failure of bearings of plummet and other makes oil pumps. There were 09 failure of bearing in FY 07-08 and 05 bearing failed in first quarter of 08-09. Original ball bearings of Plummet make oil pumps are having plastic cage and plastic spacer. Plastic cages are breaking after 2-3 months of service. This problem could be controlled at Electric loco shed, Lalaguda by replacing these bearing with 6306/3306 bearing as a part of reliablity action plan. Same problem had been faced by other sheds when they

received new locomotive from CLW. But no steps have been taken at any level to solve the problem.

Frequent openings of auxiliary motor's MCBs due to unbalance in output voltage of BUR causing quiet a few failure. Defective WRE modules of BUR are the main reason of intermittent opening of MCBs. Such failures are very difficult and to troubleshoot.

In some of the locomotives there are frequent failure of auxiliaries. In such cases quality of power output from BUR should be checked for presence of harmonics.

5. Sensors

One WAG 9 locomotive has 22 sensors:

- 6 TM speed sensor
- 6 TM temperature sensors with 2 elements each.
- 2 transformer temperature sensors.
- 2 Main converter temperature sensors.
- 4 transformer pressure sensors.
- 2 main converter pressure sensors.

These sensors are meant to give information to control electronics about various equipments to monitor their working and take other decisions, but these sensors are falling a lot.

In FY 07-08, 31 sensors failed in electric loco shed, Lalaguda and 34 failure took place in first quarter of current FY.

WAG9 locomotives are having weig and type speed sensors. Each motor has two sensors in one unit. Speed sensor mostly fails because of less amplitude of output pulses. It has been observed that for the sensor connected to electronics amplitude of pulse reduces with time. There are two sensor units are available for each motor, but in case of failure of one sensor there is no facility to switch over to other sensor either automatically or by driver. In such cases loco has to be sent to nearest shed with one bogie for changing of connector in electronics. On line failure can be avoided by making arrangement to enable the driver to switch over from one sensor to other.

Failure of temperature sensor of traction motor is also very high and this also causes isolation of one bogie. Temperature sensors are resistance thermometer transducer. Electronics monitors the resistance value and difference of value for both elements. Temperture sensors fail because of wrong fitment, poor curing and improper crimping.

Proper mixture of resin and hardner is also an important factor to get proper fitment of temperature sensor.

Pressure sensor and temperature of transformer and main converter are also failing with added problem of oil leakages.

Simple logic of reliability says that some of the sensor in this loco should be removed by modifying the software. For example temperature sensor of traction motor can be done away with, as there are current sensors available to monitor the motor currents.

6. Untrained crew and maintenance staff

It is unfortunate but true that even after 12 years we could not train enough crew and maintenance staff. Poorly trained crews are not able to troubleshoot simple problem like not building up of BP when ZBAN is ON or tractive effort is limited to 300 kN when ZTEL is ON. Many a times due to inadequate knowledge pilots are hauling the WAG 9 in dead condition with parking break in applied condition and damaging the wheel set by increasing the wheel to wheel distance. Even it is very difficult to get correct information about the failure so homingshed can guide them for troubleshooting.

Similarly in the case any on-line problem loco has to be sent to nearest 3 phase loco homing shed as trip sheds and other loco sheds staff are not trained. Now a days WAG 9 locomotives are working all over. Indian Railways and such movement increase the ineffective of loco.

Since there is no infrastructure available to train the maintenance staff, on many occasions trobleshooting is incomplete and very slow. Incomplete trobleshooting always leads to another on-line failure.

Paucity of qualified workforce which can work with this level of technology is one more hurdle that needs to be tackle urgently.

7. Maintenance Unfriendly

All major equipments of this locomotive require special jigs, machinery and plants. Main and auxiliary need special tackle for removal and installation . Valve set and transformer are to be removed and fit with the help of specially designed trolley only. For mounting and removal of aclathan ring double acting jack is necesary. Similarly TM pinion can be mounted with glycerin operated jack only.

Maintenance of these M&P is very critical as breakdowns of these are very frequent.

As usual there is lack of standardization which further accentuates the problem of spare. For example if motor of one make of OCB fails, then it is very difficult or nearly impossible to replace it with other make of motor. Same is the case with impeller and complete unit.

It is very difficult to change control cables due to there length and layout and this might have been avoided if where ever possible spare cables were provided in manufacturing stage.

8. Other Areas of Concern

Oil leakage, water leakage and failure of pneumatic brake system are also troblesome.

Oil leakage are very common from stainless steel pipe bellows, sensors, oil pumps and stuchi coupling of valve set.

Water entry from OCB air inlet duct is very heavy and causing failure of brake electronic. Water enters through air inlet of OCB due to non availability of gasket same as imported loco.

Dropping of BP pressure even if both compressors are working and consequent S/R interlock is very common in these locos. This problem has been addressed in R2003 version of software, but it is still to see the other implications of software changes.

Failure to standardize the brake system would always be an area to look for as both the available system are entirely different on component level and even there test benches are not same.

The format of Diagnostic Data set is difficult to decipher by frontline staff and always required input at supervisor and staff level. DDS format and also usage of talking station should be made user friendly.

9. Steps May be Taken

We have been projecting the WAG9 locomotive as future or electric locomotion and this locomotive has become integral part of freight operation on Indian Railways. In wake of amount of failures there is an urgent need to intervence suitably at appropriate levels to find out the technically feasible solutions. The following steps may be taken to effectively control the failure and improve the reliability of locomotive.

- Technical Audit of changes we have done in software and hardware.
- Repeated failure of electronics should be referred to the persons associated with design of the locomotive.
- Maintenance Schedules should be reviewed and revised.
- MCB-100 modification should be implemented.
- Review and revision of TSD
- Quality Audit of material.
- Incorporation of Hall Effect speed sensor.
- Switching over to IGBT based converter.

After 12 years of operation of WAG 9 locomotives we are having sufficient data related to failures and their analysis. In view of this changes and modifications we have made in various parts of the locomotives and software should be analysed in depth to ascertain the adequancy of these changes. Less than adequate know-how of software and electronics at all level warranted such technical audit.

As mentioned earlier failures of electronic cards have certain pattern. But Railways and TOT partners are not capable of carrying out any corrective modification. Therefore experts who had been associated with design of electronic cards and software development should be

consulted and asked to suggest solution to contain failures.

The entire maintenance schedules should be reviewed and revised to control mechanical failures, insulating oil related problems, ensure timely cleaning of body filters etc.

It is very hard to understand that, why is MCB-100 not available to drivers ? This battery circuit MCB has tendency of frequent tripping but due to its location drivers can not reset the MCB and invariably loco fails on every occasion. Such failures can be avoided by shifting this MCB to HB panel and giving appropriate instruction to Drivers. This modification should be implemented in all the locos immediately.

In order to avoid damage of equipments and certain type of failures trouble shooting directory should be updated. For example on tripping of one oil cooling blower driver should isolate one bogie to avoid damage to converter.

WAG-9 is our flagship freight locomotive and we can not afford to have inferior quality of material on this locomotive. On the basis of the failure inventory quality audit of certain equipment should be carried out. So supplier with poor infrastructure and quality can be eliminated . In certain cases actual performance of indigenous substitute needs to be ascertain vis-a-vis imported equipment.

In Weigand speed sensor amplitudes of the pulses reduces with time and leads to failure of the loco: These sensors should be replaced with hall effect transducers, trial of these sensors is already going on.

IGBT is more advance power electronic device and its performance in the static converter of conventional locos is far better than GTO in WAG 9 locomotive s. Process of replacement of GTO with IGBT should be expedited on priority basis.

Three phase technology is a modern technology and it is here to stay. It is nearly impossible to go back to the DC drive days so it is desirable that we should start it handling professionally.

COMMUTATOR FITMENT ON TAO-659 TRACTION MOTOR

By H.K. Ghatuary And R.K.Sahu
(Based on Project Report)

TYPES OF COMMUTATORS

There are different types of commutator used in traction services.

Classification based on external appearance, that is method of supporting commutator bars :

1. Bolted type commutator
2. Ring nut commutator
3. Spring ring commutator

Bolted type commutator is most common. The segments are tightened between the cap and shell by means of bolts screwed into the shell.

In TAO 659 bolted type commutator is used.

There are four types of commutator, which utilise the conventional VEE method of construction

1. Wedge or vee bound commutator
2. Arch bound commutator
3. Hub or drum bound commutator
4. Equi-angled commutator

Wedge Bound Commutator

In this type of commutator the pressure from the cap and shell is carried partly on the 30° surface and partly on the 3° or 6° surface of the copper. There must be clearance between the inside dia of the copper segments and the shell.

Arch-Bound Commutator

In the arch-bound commutator all pressure from the cap and shell is carried on the 30°surface. There must be clearance between inside diameter of the copper segments and the shell and also between the 3°surface of the segment and the mica cone.

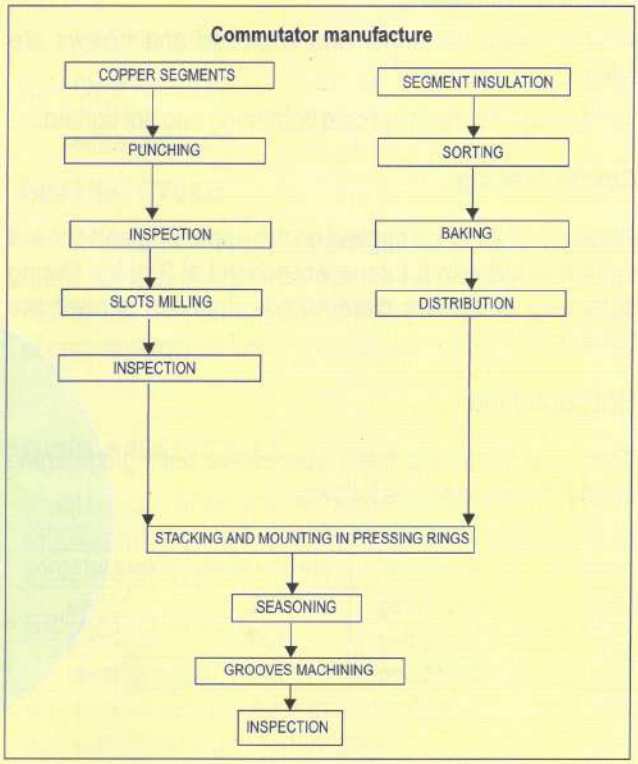
In TAO 659 motors the commutator is arch-bound type.

Hub-Drum Bound Commutator

The copper and mica segments are stacked tightly against the insulated commutator shell, then the segments are bored, still held tightly against the shell. So that there is pressure on both 30° angles.

Encastre or equi-angled commutator-

The toe of the commutator bar is machined with an angle on its outer surface equal to that on its inner surface.



MANUFACTURE OF COMMUTATOR

TAO 659 Commutator is made of 276 copper bar and 276 mica segments. A circular hole of 30-mm dia is punched in each of the copper segments at the centre. Slots are milled on the riser portion of the copper segments for accommodating the leads of armature conductors.

The insulation segments are baked at 120° for 12 hours in an oven.

Mica segments come in packs sorted in 5 categories : a-0.02, a - 0.01, a, a+0.01, a+0.02.(a being the average thickness).

For a given commutator a pile of 276 micas comprising alternatively 1 mica a-0.02, 1 mica a+0.02 etc is arranged.

Stacking and mounting in pressing ring - the jig consists of two rings and 6 blocks. First, lower ring is placed on the assembly table and then blocks are placed. Copper segments and mica segments are stacked one by one. During stacking, vertically of the segments is checked using a special square.

After stacking the upper ring is placed and screws are fitted.

Tightening - it consists of cold tightening and hot tightening

Cold tightening :

Pressure of 90 ton is applied on the upper ring and screws are tightened with a torque wrench set at 9 m-kg. During tightening of screws diametrically opposite screws are tightened.

Hot tightening:

After cold tightening three successive baking/tightening cycles then be made as follows.

cycle no	oven baking	pressing effort	screws tightening
1	12h,200-Deg	120t	12m-kg
2	12h,200-Deg	120t	12m-kg
3	12h,200-Deg	144t	12m-kg

Final cold tightening:

After 24 hours (minimum) cooling, pressing under 144 tonnes is done and screws are tightened with the torque wrench set at 14.5 m-kg.

After the seasoning of the commutator V-grooves are turned on a machine.

Dimensions in TAO 659 commutator

Segment height	148 mm
Riser top diameter	500 mm
Internal diameter	255 mm
Rough diameter	390 mm
Riser width	17 mm

Commutator Material :

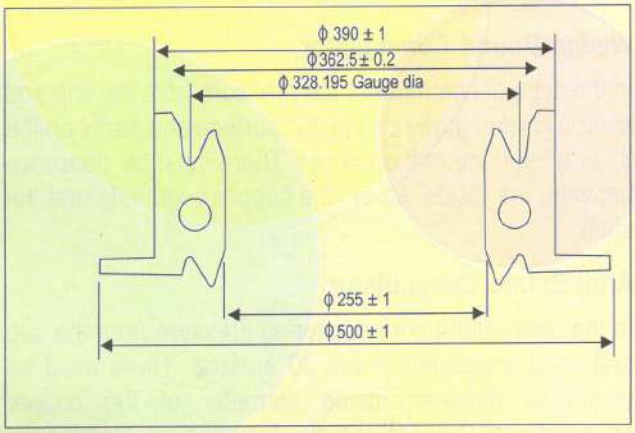
Bars :Silver-bearing copper , Silver content 0.05 % to 0.08 %

Separator : Shellac bonded mica splitting.

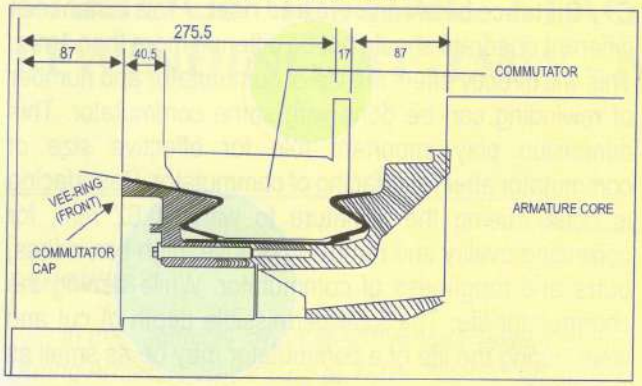
Insulating VEE rings: large mica splitting bonded with synthetic resins.

Steel VEE rings: made of high strength alloy forged steel.

COMMUTATOR CROSS SECTION



ARMATURE SHAFT



Seasoning can be classified as:

1. STATIC SEASONING
2. DYNAMIC SEASONING

STATIC SEASONING

The seasoning include the tightining of commutator bolt in cold and hot condition. Initial tightning of screw with the torque wrench set at 2mkg in cold condition.The assembly is heated to 155°C and the steel vee cones are pressed by hydraulic press and simultaneously tightned. This heating and coating cycle is reapeated thrice. Each cycle of heating tightning cooling tightening is known as CTH.

Detail seasoning cycle for TAO659 commutator :

OPERATION	HEATING TEMP	HEATING DURA-TION	temp. attend by commutator before pressing.	temp after tightening	pressure (tonne)	torque (mkg)
Ist hot tightening	155°C	12 hrs	150°C	140°C	NA	5
Ist cold tightening	ambient	---	ambient	ambient	---	5
IInd hot tightening	155°C	12 hrs	150°C	140°C	50 to 53	7
IInd cold tightening	ambient	---	ambient	ambient	---	7
IIIrd hot tightening	155°C	12 hrs	150°C	140°C	NA	9
IIIrd cold tightening	ambient	---	ambient	ambient	---	9

After each cycle (CTH) the armature is checked for following dimensions.

1. Proper line up of commutator with respect to centerline of core slot.
2. Riser run-out i.e. the distance between the commutator from surface and shaft face with a dial indicator
3. Skewing of commutator with respect to axle.
4. Distance between core and riser.

Dynamic Seasoning

Due to the instability of shellac at elevated temperatures it is no longer use for building modern heavy-duty commutators . Commutator assembled with mica vee ring and mica separator bonded with shellac required "rotational or dynamic seasoning" to effect some measure of mechanical stability prior to being placed in service. This rotational seasoning consists of alternate heating, grinding and cooling at high speed, followed by pressing of the commutator assembly in press. This process is repeated until a degree of smoothness of the commutator surface is attained.

Dynamic seasoning consist of three cycle.

1. Heating cycle
2. Over speed cycle
3. Breaking cycle

HEATING CYCLE

In this part of cycle armature is rotated inside the oven. Armature is rotated with the help of motor between 100 to 150 rpm for specified duration. After this tightening of commutaror bolt with the measurement of dimension.

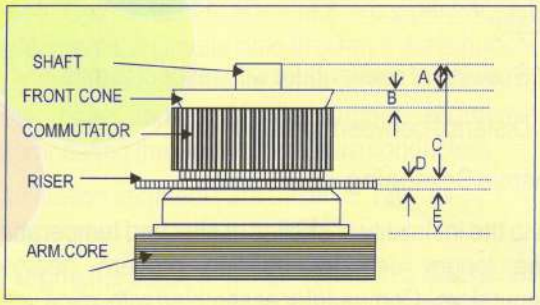
OVER SPEED CYCLE

In this cycle armature is rotated at desired overspeed (3000 rpm) for 2 to 5 minute as set on timer. During this cycle heater is put off.

BREAKING CYCLE

In this cycle motor is roated speed and switch off. Armature is rotating for 3 to 4 minute due to inertia. After this final tightening of commutator.

IMPORTANT DIMENSIONS OF COMMUTATOR FITMENT.



DISTANCE	STANDARD dimension (mm)	AFTER CTH-1	AFTER CTH-2	AFTER CTH-3
		0° 90° 180° 270°	0° 90° 180° 270°	0° 90° 180° 270°
A	87			
B	40.5			
C	275.5			
D	14.0/17.0			
E	87.0/84.0			

A Distance of commutator cap from shaft face measured at every quadrant: This distance should be uniform around the periphery for proper fitting of rotor assembly in stator. If it is not uniform or less then design value i.e. 87 mm for TAO659 cause insufficient.

B Distance between commutator front and commutator cone : In arch bound commutator there is no 3° pressure on segment, the assembly is free to rock on the 30° angle like a ball and socket joint, so that extreme care must be taken when assembling or tightening arch bound commutator to keep the segment and cap parallel with the shell. If cap, segments and shell are not kept parallel, the commutator brush surface will get eccentric when commutator is heated.

C Distance between core and riser :- This distance at different quadrant should not be differing more than 1mm. This will directly effect the life of commutator and number of rewinding can be done with same commutator. This dimension play important role for effective size of commutator after resurfacing of commutator. Resurfacing is done trueing the armature to within 0.02 mm, for correcting ovality and removing groove, high bar, ridges, burrs and roughness of commutator. While turning the commutator life. The total permissible depth of cut and wear during the life of a commutator may be as small as only 8mm.

D Width of riser :

New commutator 17mm

Old commutator 14mm

Condemning limit 8mm

With new segment riser width 17mm 3 times rewinding is possible. For each rewinding 3mm depreciation of riser is due to TIG welding and resurfacing of riser face.

E Distance between riser and armature core

86+1mm, 86-2mm, when riser width 17mm

84+3mm, 84-2mm, when riser width 14mm

SUGGESTION

Since the dynamic seasoning is actual simulation of working condition , static seasoning as well as dynamic seasoning should be carried out which will help in less failure of commutator assembly.

1. No chance of ovality during service.
2. Chance of skewing in survice is almost nil.
3. No chance of runaway of commutator segment.

IRIEEN JOURNAL

VARIOUS TESTING STAGES DURING ARMETURE REWINDING AT TMW - NASHIK

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(IRSEE, Based on Project Report)

SYNOPSIS

In this technical report titled "Various Testing Stages During Armeture Rewinding at TMW- Nashik" an attempt has been made to compile the various testings that are carried out at different quality assurance points in the material flow process during rewinding of defective armatures of traction motors which come to TMW/NK. A brief theory and description of different electrical tests are also given subsequently. This will help in understanding the need of the test in better way. It was also tried to find out the relevance of the tests at different point of time.

Finally some recommendations have been given for optimisation of the testing process with the manufacturing process in order to reduce time and cost of production. Simultaneously some of the suggestions are for addition of some tests, which necessarily will guarantee better performance of traction motors in the field.

1. INTRODUCTION

Stage testing means carrying out different mechanical and electrical tests, to ensure that the trouble faced during operation are minimised. This is resorted to in the case of Traction Motors also, not only during their manufacture but also during their rewinding . It is better to be aware of the weakness during rewinding itself, where it could be repaired, than to face a failure in service. No short cuts should be resorted to during the process of stage testing.

At TMW, Nasik, rewinding of traction motor armatures is a major activity. During the process of rewinding an armature passes through different inspection booths.

The details of the different tests carried out at these booths have been discussed in the succeeding chapters.

2. STAGE TESTING

The present practice of in-depth inspection and testing of a machine or a machine part during its process of manufacture is equally applicable to the manufacture of traction motors. The stage testing during the process of manufacture ensures the quality of the product at any instant and simultaneously clears it for the next stage in the material flow process. In this way the intermediate stage testings will ensure detection of any flaw or discrepancy in the material after some work has been done on it during the process of manufacture, and further addition of costly materials and man-hours, which could go to waste.

If the fault is detected in the final inspection stage and is thus avoided. Hence stage testing during any manufacturing process is beneficial by maintaining quality as well as ensuring economy by preventing loss of materials.

Due to the above advantages different stage testing techniques have been introduced by TMW during the process of armature rewinding. Tests are carried out on the armature in different sections such as AW-I, AW-II , commutator repair section etc. During the rehabilitions process in the concerned section, before dispatching it to the subsequent section.

The tests carried out are of varying nature ranging from visual inspection to several electrical tests and mechanical checks. The tests, which are carried out in different sections, are noted below as per the material flow process in the shop. The details of different tests have been given.

STAGE TESTING AT DIFFERENT SECTIONS

1. INCOMING INSPECTION OF ARMATURE :

- Before starting the rewinding process of the armatures received form the PCO section the following activities are carried out:

- Visual checking of the armature: the condition of the commutator, shaft dimensions etc. are observed and the proforma, given in Annexure-I is filled up. The type of band and welding are also indicated.

- Insulation resistance of the armature with respect to the shaft is measured with a 1000V megger.

- Bar to bar test of the commutator is carried out.

- Surge comparison test is carried out ot detect any inter turn shorts.

- Ultrasonic test of the shaft is carried out to detect any cracks in the shaft.

- **The following dimensions are measured :**

i) Comm.Diameter : This should be between 365mm and 380mm. If the diameter is less than 365mm then the commutator is condemned .

ii) Pinion End :

- Shaft end to libring : should be between 242.5 and 244 mm
- Libring length : should be between 49 and 52mm.
- Collar length should be between 15.5 and 17.5 mm.

iii) The race diameters at the pinion end and commutator end are also determined :

b) Commutator End :

- Shaft end to steel Vee length : should be between 87 and 90mm
- Steel Vee length : should be between 36 and 39mm
- Shaft end to Riser length : should be between 272 and 275mm.

I. RESHAFTING SECTION:

If a shaft is defective then it is sent to this section. The different checks/tests carried out are as given below :

- Dimensions as per the diagram are checked after the machining of the shaft is done.
- The ovality of the shaft is checked . This should not exceed 0.015 mm.
- Visual checking of the armature punching bars for smooth surface.
- Ultrasonic testing of the shaft.

II. STRIPPING SECTION AW-I :

After stripping of the commutator and before core cleaning the following tests are carried out :

- Core slot mouth clearance (C.S.M.) is checked by gauge. This should not exceed 8.8 mm.
- Core loss test is done by applying 8V AC at the shaft ends and noting down the current passing . It should be within some prespecified value, typically 150.

After core cleaning the following stage tests are carried out:

- C.S.M. by standard gauge should not exceed 9 mm.
- Wedge groove is checked by standard gauges.
- Slot width checking is carried out by standard gauges.
- Commutator testing by H.V. test, carried out at 8kV for 1-min. duration
- Bar to bar test is carried out at 800V.
- The copper and mica segments are checked visually.
- Inspection is carried out after ground insulation and varnishing.

The above tests are carried out after commutator repair, if required , is done and before sending it to AW-II section.

III. COMMUTATOR REPAIR SECTION :

In this section the following activities are carried out:

- Checking the commutator for correct number of segments e.g. 276 for TAO659.
- Various distance of the commutator with respect to the shaft end are verified.
- Centering of commutator by ovality testing is carried out. The ovalilty should not exceed 1mm.
- Bar to bar mica insulation checking is carried out at 500V flash.
- H.V. testing of all commutator segments connected together and between earth is carried out at 8kV applied for 1min.

IV. COIL FORMING SECTION:

In AC-I section during and after coil formation the following inspections are carried out :

- Visual inspection of conductors after conductor cutting for good adhesion and for ensuring absence of insulation defects.
- After loop forming the gauge should fit freely. It should neither be too tight or too loose.
- Armature coils thickness after flattening should not exceed. 1.3 mm.
- Visual checking after coil forming and annealing (done by keeping the coil in the oven at 150C for 12 hours). There should be no insulation damage on adjacent conductors at the same place. No copper should be visible on the slot portion.

V. COIL INSULATION SECTION

In AC-II section, after complete insulation of the coil the final testing is carried out as follows :

- The dimension of each oil is checked on the slot portion with a gauge e.g. for TAO-659 the width should be 7.27 mm and depth should be 17.67 mm.
- The thickness of the evolute is checked , the maximum admissible value being 11.5 mm.
- H.V. test is done between the conductors at 1 kV flash.
- H.V. test is done between the slot portion and earth in a fixture. This is done by applying 9 kV for 1sec.
- Dielectric test (H.V. test) is carried out between the evolute and earth . In case of TAO-659 it is done at 4kV applied for 1sec.
- Visual checking is done to ascertain whether tape is torn, insulation is overstuffed etc.

VI. REWINDING SECTION:

In AW-II section after placing the equaliser coils the following inspection stages are carried out :

- Dielectric test is carried out between adjacent conductors by 750 V flash.
- Checking for equaliser coil continuity.
- High voltage testing between equaliser coils and ground after applying putty by using 7kV for 1 minute.
- High voltage testing between armature coils and ground after placing power coils by applying 6.5 kV for 1min

In AW-II section :

- H.V. between armature coil and ground after temporary banding by applying 6 kV for 15 seconds.
- H.V. test between armature coils and ground after wedging by application of 5.5 kV for 1 min.
- Surge test between bars carried out at 800 V.
- Drop test before TIG welding. The tolerance provided is ± 3 S.D.
- Surge test is done after TIG welding by application of 800V.
- Drop test is carried out for equaliser pitch. The permissible tolerance is ± 3
- H.V. test is carried out between armature coils and ground after final banding, using 5 kV for 1 min.
- Surge test at 800 V is carried out after final banding.
- Drop test is carried out after final machining of the commutator , with a tolerance of ± 3 S.D.
- D. C. H. V. testing is done before and after impregnation.

- Tan delta test of armature is carried out.

VII. MOTOR ASSEMBLY SECTION

The armature is subjected to the following stages of testing :

- Checking the ovality of the commutator while conducting the no load test, by running the motor for 2 hours in one direction and then for 2 hours in the opposite direction. Each time the ovality is checked.
- One hour temperature rise test is carried out using the load test.
- High speed testing of the commutator, while hot, is carried out for detecting any abnormality.
- H.V. testing is carried out after dismantling the armature.

3. ELECTRICAL TESTS

In order to ensure the reliability and trouble free operation of the traction motors, which are subjected to severe operating conditions during running, it is necessary to test them thoroughly during rewinding . During the process of rewinding the traction motor is subjected to the following tests :

- Measurement of insulation resistance,
- High voltage test,
- Bar to bar conductor resistance and equaliser resistance test,
- Surge comparison test and
- Measurement of tan delta.

3.1 MEASUREMENT OF INSULATION RESISTANCE

H.V. testing may be damaging for the windings, especially if the leakage currents are high owing to the absorption of moisture etc. Therefore, it is advisable to first measure the insulation resistance with a megger, before carrying out H. V. testing.

In case of faults in the insulation, the leakage currents may be higher than the expected values. The megger may fail in detecting such faults. In such cases it is recommended that the H.V. test should be done by gradually raising the rest voltage in steps of 250V , beginning from 500V , till the specified test voltage is reached. The pattern of rise of leakage current with voltage should be linear. In case there is a non linear rise or sudden jump in leakage current at some stage, the armature is taken to be defective and should be taken up for rewinding.

3.2 HIGH VOLTAGE TEST

Standard AC high potential tests are used to verify the adequacy of the insulation . The leakage current during H.V. tests using 50Hz, AC sets depends on the following factors.

i) Capacitance of the test object between power conductors and armature core etc. with the insulation as the dielectric medium.

ii) Leakage current through the dielectric medium due to conductance and

iii) Leakage current through the creepage paths.

The value of capacitive current for TAO-659 armature and complete motor are of the order of 30 mA and 45 mA respectively. The value of the other two components depends on external factors like :

i) Extent of moisture present in the insulation,

ii) Temperature of the winding,

iii) Dust and dirt on the creepage surface and,

iv) Type of insulation.

3.3 BAR TO BAR CONDUCTOR RESISTANCE AND EQUALISER RESISTANCE TEST

Bar to bar resistance check is an important test for

detecting defective joints in the commutator riser. In case any high resistance joints are not detected then several defects may develop while in service e.g.

i) Overheating of coils due to unequal sharing of currents between different parallel paths,

ii) Overheating of the joints possessing high resistance due to increased I2R losses in that location,

iii) Gradual worsening of commutation due to further worsening of joint resistance and unequal sharing of current,

iv) Flash overs due to bad commutation,

v) Major defects such as earthing and BBCR, if the armature is allowed to remain in service any further.

Equaliser winding is used in the case of lap wound armatures. In case of a break in equaliser connection a high resistance may appear across adjacent bars. This will result in maloperation of the armature.

For detecting such faults the resistance between adjacent segments is measured with the help of a micro-ohmmeter. The average and standard deviation of the microohm resistance is determined. The difference between the average and any of the readings should be within ± 3 S.D.

- Calculate the actual mean of the series i.e.X.
- Take the deviations of the items from the mean i.e. find (x-x). Denote these deviations by X.
- Square these deviations and obtain the total i.e. {X2.
- Divide { X2 by the total number of observations i.e. N and extract the square root. This gives the value of standard deviation.

3.4 SURGE COMPARISON TEST

This test is conducted to detect and locate inter-turn insulation defects in the armature winding and the field coil using a comparison method, with the help of a surge analyser.

The test voltage is applied at power frequency and varied between 500V and 3000 V AC in stages of 500V. coils using a comparison method, with the help of a surge analyser. The voltage is applied to two identical coils and the resultant current wave from each coil is displayed on the oscilloscope. If the insulation of both the coils is good only one stable waveform is observed on the oscilloscope. In case any of the coils has a high resistance, short or insulation defect, two waveforms are observed on the oscilloscope. This test is conducted thrice on an armature during rewinding i.e. before and after soldering/TIG welding and during final testing.

3.5 TAN DELTA TEST

When an AC voltage is applied to a perfect capacitor, the resulting current leads the voltage by 90. However, in case of a capacitor with losses, this angle is less than 90, and may be denoted by 0. The cosine of 0 is called power factor or dissipation factor. The angle that the current is short of 90 i.e. minus 0 is called delta. For small angle, typically less than 10, the tangent of 0 is approximately equal to the cosine of 0. This implies that power factor, dissipation factor and tan delta are within 1 % of each other for dissipation factors less than 0.1. Since most of the bridge instruments measure tan delta, it is used as the guiding factor.

A large number of failures, on electrical apparatus, owing to deterioration of insulation, can be avoided by proper evaluation of the quality of machine insulation through tan delta measurements.

Chemical deterioration, contamination by dust grease etc. leakage through cracks and oversurfaces, ionisation at operating voltages etc. can be ascertained through Tan delta measurements.

Tan delta measurements are carried out after Vacuum Pressure Impregnation, followed by baking and cooling to room temperature . The measurements are carried out between commutator (with all the segments shorted by a copper shunt) and the armature shaft.

The test voltage is applied at power frequency and varied between 500V and 3000 V AC in stages of 500V.

The insulation of the armature is considered to be healthy if :

- Either the Tan delta value at 1.0 kV does not exceed 2%,
- Or the difference between Tan delta values at 3kV and 1 kV does not exceed 2% subject to the condition that Tan delta at 3kV does not exceed 4%.

If case either of the above conditions is not satisfied the armature is baked again and Tan delta measurements are repeated.

If the tan delta values at 1 kV and 3kV exceeds 4% or 6% respectively, then the armature is impregnated and baked followed by a repetition of tan delta measurements.

If still there is no improvement in Tan delta values, the armature may be permitted for service but shall be kept under observation.

3.6 NO LOAD TEST

A light run test is carried out on traction motors, prior to conducting one hour temperature rise test, to check bearing noise, vibration and also the peak temperature rise of bearing . The test is conducted for one-hour. The speed at which the test is carried out on various motors alongwith voltage and current taken is shown below.

TAO-659	1500RPM	90-100V	50 60AMPS
HS15250	1100RPM	115V	50AMPS

3.7 ONE HOUR TEMPERATURE RISE TEST

This test is conducted to determine the maximum temperature rise of all the windings, which can occur under working conditions. In this test the voltage and current applied are that of one hour rating of motor and the ventilation level is same as is available in service. The temperature rise of the commutator is measured by electrical theremometer and on armature and field windings by resistance method. The voltage, current and rpm of the test for different motors are given below.

TAO-659	1090RPM	750V	855AMPS
HS15250	877RPM	750V	960AMPS

RECOMMENDATIONS

After having closely studied the whole process of armatures rewinding for Traction Motors and the several tests, stage inspections that are carried out in different quality assurance points in the respective sections it is felt that in some places there is a need for inclusion of some tests and somewhere some tests may be done away with as it seems to be a little repetitive one.

It is a well, established fact that the life of electrical insulations get deteriorated by some time whenever it is subjected to some high voltages whether it may be during testing phase or undergoing actual over voltage when in operation. The life of electrical insulation also gets affected if it gets some shock or vibrations. So keeping in mind the above the following alterations in the stage testing process may be done in a phased manner.

1. Since coils are already cleared from AC-II section after testing, the HV test on the coil can be done after placement of wedges in the slots during the winding process in AW-II section instead of doing HV test each time after placement of coils, temporary banding and wedge placing.

2. Surge test is done on the armature coils to detect inter turn short before TIG welding and after TIG welding . But it would be better if the armature is handled carefully during transportation from one section to another and surge test after the TIG welding is eliminated as there is a little chance of coils getting damaged during TIG welding process. Surge test after the permanent banding should continue.

3. Core loss test must be done for all armature during rewinding process as the damage of insulation in between the core stampings will result in localised heating due to eddy current in that part and subsequent weakening of insulation during normal operation of traction motors. This will lead to burn out of insulation in long run.

4. The continuity test of the equaliser coils after placement of the coils is done manually by counting the number of segments in the commutator. In this process an error may occur in counting as human element is involved and the armature may fail finally.

So making a standard test probe with known distance across the commutator segments for TAO-659, HS-15250 armature separately will ensure correct continuity test with hundred percent reliability.

5. A sample of the process sheet for armature rewinding presently in use is shown in the **Appendix.** In this sheet all the possible works to be done is given sequentially with spacing for details of work done, artisan's name etc. But , initially the work to be done is not mentioned. Instead of this a little change in format would serve the purpose in a better way. In a small space provision may be given to indicate the type of work to be carried out by putting "Tick" in a box against the work item and the details of work that has been done may be noted separately in some "remarks" column. In this way a lot of saving in paper is possible.

6. In Ultrasonic test of the shaft the threaded hole portion at the end does not allow Ultrasonic test to be done in that part of shaft axially, which covers a substantial part of the shaft. The holes may be made in either side in such a way that holes from one end does not come in line with the holes from the other end. Then Ultasonic test can be carried out from both the ends of the shaft by covering the whole cross section of the shaft.

TRACTION MACHINEWORKSHOP-NASHIK ROAD, CENTRAL RAILWAYS

PRILIMINARY INSPECTION

IR Value as Received :	Commutator Inspection :	Commutator dia :	
Visual Inspection of Armature :			
Probable cause of Failure :			
Location of Failure :			
Past History of Armature :			
Tests carried out before stripping HV :	Drop Test :	Surge Test :	

STAGE TESTING PARTICULARS

Sr. No.	STAGES OF TESTING	STANDARD TEST VALUES				TEST RESULTS							
		4939 AZ	TAO 659	H.S.1091	253 BX		I	Date	II	Date	III	Date	Name of Insp.
1	Commutator IR Value	200M.ohms	200M.ohms	200M.ohms	200M.ohms								
2	High Voltage between commutator & Ground	8 KV	8 KV	7 KV	6 KV	IR value							
		15 Sec.	1 min.	15 Sec.	15 Sec.	Leakage current							
3	High Voltage between commutator bars												
	before applying putty	1000V	1000V	375 V	800 V								
	after applying putty	1000V	1000V	500 V	800 V								
4	High Voltage between Equaliser conductors												
	before applying putty	750 V	750 V	-	500 V								
	after applying putty	750 V	750 V	350 V	500 V								
5	High Voltage between Equaliser coils & Ground	7 KV	7 KV	-	5.5 KV	IR value							
	after applying putty	15 Sec.	1 min.	-	15 Sec.	Leakage current							
6	Equaliser continuity / Drop Test												
7	High Voltage between armature coils and ground	6.5 KV	6.5 KV	6.5 KV	5 KV	IR value							
	after placing power coils	15 Sec.	1 min.	15 Sec.	15 Sec.	Leakage current							
8	High Voltage between armature coils and ground	6 KV	6 KV	6 KV	4.5 KV	IR value							
	after temporary banding	15 Sec.	15 Sec.	15 Sec.	15 Sec.	Leakage current							

ARMATURE Number : **TYPE :** **LAST RW DATE :** **DATE RECEIVED :**

Appendix

Sr. No.	STAGES OF TESTING	STANDARD TEST VALUES				TEST RESULTS							Name of Inspector
		4939 AZ	TAO 659	H.S.1091	253 BX		I	Date	II	Date	III	Date	
9	High voltage test between Armature coils and ground	5.5 KV	5.5 KV	5.5 KV	4.5 KV	IR value							
	After wedging	15 Sec.	1 min.	15 Sec.	15 Sec.	Leakage current							
10	Surge test between bare	800V	800 V	500 V	500 V								
11	Drop test before dip-soldering /TIG welding	± 3 X	(Standard	Deviation)									
12	Drop test after dip-soldering/TIG welding	± 3 X	(Standard	Deviation)									
13	Surge test after dip-soldering/TIG welding	800V	800 V	500 V	500 V								
14	Drop test of equaliser pitch	± 3 X	(Standard	Deviation)									
15	High voltage test between Amature coils and ground	5 KV	5 KV	5 KV	4 KV	IR value							
	After final banding	15 Sec.	1 min.	15 Sec.	15 Sec.	Leakage current							
16	Surge test final banding	800V	800 V	500 V	500 V								
17	Drop test after final maching of commutator	± 3 X	(Standard	Deviation)									
18	Dia of commutator Maximum	422.5mm	380 mm	750 mm	323.9 mm								
	Dia of commutator Minimum	395 mm	364 mm	730 mm	304.8 mm								
19	D.C.HV testing Before Impregnation												
	After Impregnation												
20	Tan delta value Before Impregnation												
	After impregnation												

ARMATURE Number : TYPE :

ARMATURE No.

Sl no.	date	name of artisan	nature of work	actual work carried out	Inspectors signature	sl. no.	date	name of artisan	nature of work	actual work carried out	inspectors signature
11			slot insulation			1			bearing	old/new	
12			shims						CE	old/new	
13			temp. banding						PE		
			size of wire			2			radial clearance	CE_____ PE_____	
			tension						after assembly		
14			slot wedges	make		3			no load test		
15			TIG welding/	gas used							
			dip soldering								
16			impregnating varnish			4			load test		
			dip/vpi						temp rise (arm)		
									any findings		
17			final banding								
			material								
			tension								
18			commutator ovality						despatch		
				C E_____ P E_____					Asssembled	stator no.	
19			balancing			5					
				unbalance of C E ____P E__					armature	only armature is sent	
20			final varnish spray								
						Any special information to intimated to owning railway for keeping under observation					

Final Inspection of armature

offeared by_____ date_____ inspected by_____ date_____

TRACTION MACHINE WORKSHOP C.RLY. NASHIK ROAD-ARMATURE REWINDING

Preliminary Inspection

ARMETURE REWINDING PROGRESS **ANNEXURE - I**

Condition of commutator :	sr. no.	date	name of artisan	nature of work	actual work carried out	Inspection
TIG welded / soldered						
windings :	1			reshafting		
wedges:						
bands						
shaft dimensions ultrasonic test :	2			coil stripping		
test results initial final						
I R:						
H V:	3			core cleaning		
drop test:						
comm. dia:	4			core repair/restacking		
tam delta						
defects noticed deficiencies	5			core spray varnishing		
before stripping :						
	6			comm. repair		
after stripping :						
	7			ground insulation		
	8			equaliser coil	make	
work to be carried out :						
	9			putty	make	
	10			power coil placing		
				conductor	make	
				wrapper	make	

armature no. _____ type _____ last rewound date_____ date received_____ date_____

stator no. _____ owning railway_____ assembled in stator no. _____

ELECTRICAL TEST FOR ARMATURES DURING REWINDING **ANNEXURE - II**

Sr. No.	Stage	TAO - 659		133-AY		253 BX		4939 AZ	
		Voltage (V)	Duration	Voltage (V)	Duration	Voltage (V)	Duration	Voltage (V)	Duration
1	2	3	4	5	6	7	8	9	10
1.0	**Commutator**								
1.1	Between adjacent segment before applying putty	500	Flash	500	Flash	500	Flash	500	Flash
1.2	Between adjacent segment after applying putty.	450	"	450	"	450	"	450	"
1.3	Between all segment connected together and earth	8000	60 Sec.	7000	15 Sec.	6000	15 Sec.	8000	15 Sec.
2.0	**Armature Coil**								
2.1	Between adjacent conductor leads	800	15 Sec.	1000	Flash	1000	Flash	1000	Flash
2.2	Between all conductore at slot portion and earth into fixture	9000	1 Sec.	9000	"	7000	"	9000	"
2.3	Between evolute and earth	4000	1 Sec.	-	-	-	-	-	-
3.0	**Equalisers**								
3.1	Between adjacent conductors on completely finished bundles before mounting on the armature	800	5 Sec.	-	-	-	-	-	-
4.0	**Armature**								
4.1	Between adjacent conductore after mounting and baking equalizers.	400	Flash	400	Flash	400	Flash	400	Flash.
4.2	Between all the equalizer conductors connected together and earth	7000	60 Sec.	-	-	5500	15 Sec.	7000	15 Sec.
4.3	Continuity of equalizer	-	-	-	-	-	-	-	-
4.4	After mounting armature coils, between all conductors connected together and earth	6500	1 Sec.	6500	15 Sec.	5000	15 Sec,	6500	15 Sec.
4.5	After temporary banding between all conductors connected together and earth	6000	60 Sec.	6000	"	4500	"	6000	"
4.6	After mounting slot wedges between connected together and earth	5500	"	5500	"	4500	"	5500	"
4.7	Final tost, between all conductors connected together and earth	5000	"	5000	"	4000	"	5000	"
5.0	**Surge voltage tost between adjacent segment:**								
5.1	Before and after TIG welding and at the time of final testing	800	-	500	-	500	-	800	-
6.0	**Measurement of resistance between adjacent segments :**								
6.1	After TIG welding and at the time of final testing								
7.0	**Tan delte test :**			± 3 S.D.					
7.1	At the time of final testing								

EFFICIENCY TRENDS IN ELECTRIC MACHINES AND DRIVES

By B.C. Mecrow and A. G. Jack
(University of Newcastle, UK)

Abstract

The key challenges to increased efficiency in systems driven by electrical machines lie in three areas: firstly, to extend the application areas of variable-speed electric drives through reduction of power electronic and control costs: secondly, to integrate the drive and the driven load to maximise system efficiency: Finally, to increase the efficiency of the electrical drive itself.

By adopting known, proven concepts it is possible to dramatically increase the efficiency of systems driven by electrical machines and reduce total electricity consumption by over 7%. Some of this improvement arises from the efficiency of the machine, but the majority is due to the improved system efficiency, which can be achieved with a variable-speed drive.

Almost all electricity in the UK is generated by rotating electrical generators, and approximately half of that generated is used to drive electrical motors. Hence, efficiency improvements with electrical machines can have a very large impact on energy consumption. In the short to medium term, efficiency gains within electrical machines will result from the development of new materials and construction techniques.

Approximately one-quarter of new electrical machines are driven by variable-speed drives. These are a less mature product than electrical machines and should therefore see larger efficiency gains over the next 50 years. Advances will occur, with new types of power electronic devices that reduce switching and conduction loss.

With variable-speed drives, there is complete freedom to vary the speed of the driven load. If fixed-speed machines were replaced with variable-speed drives, for a high proportion of industrial loads, this could give 15–30% energy savings. The potential efficiency improvements within the driven load are projected to save the UK 15 billion kWh per annum which, when combined with the motor and drive efficiency gains, amount to a total annual saving of 24 billion kWh.

1 Introduction

Electrical machines have advanced significantly in recent years due to the introduction of new materials. New electrical steels have reduced losses and rare-earth permanent magnet materials have provided a 'lossless' source of magnetic flux. Recent advances in construction methods have reduced winding losses, so there is a continued trend to increase efficiency. For large electrical machines, efficiency is already high and so, although significant, the potential gains are limited. Greater gains are possible in smaller machines, which may be only 50% efficient.

Variable-speed drives are created when a motor is combined with a power electronic converter. By introducing variable speed to the driven load, it is possible to optimise the efficiency of the entire system and it is in this area that the greatest efficiency gains are possible.

This paper has three main sections – one covering the statistics of energy consumption and current predictions of possible savings using existing technology; a second covering the current state of the science, and a final one on future, more long-sighted possibilities.

2 Energy consumption

UK energy consumption statistics published by the Department of Trade and Industry) give a breakdown of energy consumption by fuel, by sector and by final end use, but do not explicitly reveal the energy consumed by electrical motor-driven systems. Studies promoted by the

European Commission (De Keulenaer et al. 2004; Haataja and Pyrhonen 1988; European Commission Joint Research Centre; EU SAVE II Project. 2001) state that motor-driven systems use 65–70% of all electricity consumed by industry, whil in the US it is estimated to be 67%. It is likely that these statistics will also be representative of the UK. Walters (1999a, 1999b) further reports that more than half of all electricity consumed in the UK is used to drive electric motors.

De Keulenaer et al. (2004) projected that, by switching to energy-efficient motor systems, EU industry would save:

- 202 billion kWh in electricity consumption (approximately 7.5% of that consumed in all sectors)
- £3–6 billion per annum in operating costs
- £4 billion in environmental costs
- 79 million tonnes of CO_2 emissions (one quarter of the EU's Kyoto target)
- A 45-GW reduction in the need for new power plant capacity
- 6% reduction in energy imports.

These figures refer to industrial savings alone: savings in the domestic, service and transport sectors could also make equivalent contributions.

Electricity consumed in the UK was 12.8% of the total in the EU in 2003 and so UK estimates can be extrapolated accordingly.

3 Current state of the science

Industrial motor systems are dominated by induction motors running at effectively constant speed. Variable-speed drives, in which the speed of the machine is controlled by a power electronic converter, are taking an increasing size of the market and in 2004 accounted for 25% of new systems (de Almeida et al. 2005). The efficiency of the electrical system in isolation will first be considered, before progressing to the entire system where, with the addition of variable-speed drives, much larger energy savings can be made.

3.1 Generation

Large turbogenerators of 100–660 MW rating supply the vast majority of the UK's electricity. These are wound rotor synchronous machines whose efficiency is over 98%. The very high efficiency arises by virtue of their very large size, with designs only changing marginally in the last few decades as newer, low-loss materials emerge.

There is much more diversity in electricity generation from renewable resources. Most wind generators are doubly-fed induction machines, fed through a step-up gearbox, but direct-drive permanent magnet generators are emerging as an alternative. With direct-drive permanent magnet systems, the efficiency of the generator is increased, and the gearbox losses are eliminated, but additional power electronic converter losses are introduced, and the system costs rise due to the large mass of the low-speed generator.

3.2 Electric motors

The efficiency of an electrical machine is a complex function of machine type, size, speed of operation, loadings, materials and operating regime (Auinger 1999, 2001; Boglietti et al. 2004; Rooks and Holmquist 2002; Umans 1989). The industrial market sector for fixed-speed machines is completely dominated by the induction motor, whose efficiency typically ranges from 76.2% at 1.1 kW to 93.9 % at 90 kW (European Commission Joint Research Centre Other market sectors, such as white goods, power tools etc., mainly utilise smaller, commutator machines, whose efficiency is typically 50% or less.

The principal sources of loss in a mains supplied induction machine are as follows:

stator winding loss, which comprises the dominant source of loss in small machines. It comprises around 60% of the total full load loss in the sub 1 kW range, falling to 25% at 1 MW and above.

lamination iron loss, due to hysteresis and eddy currents, which accounts for approximately 20% of full load loss. This loss does not generally decrease during operation at reduced load, thereby giving low efficiency in machines operating at light load.

rotor winding loss, due to losses in the aluminium cage rotor, which are strongly load dependent and amount to approximately 20% of full load loss.

stray losses, which are due to a number of effects, including induced eddy currents in the stator frame. These are insignificant in machines of less than 10 kW, rising to almost 20% of loss in machines of 1 MW.

friction and windage, including bearing loss, which is less than 5% of total loss in machines of 10 kW, rising to 20% in machines of 1 MW.

Efficiency band classifications (I, II and III) have been developed in accordance with IEC 34-2 (in which the highest efficiency, class I, is typically 3% greater than that of the standard class III, as the total losses are reduced by about one-quarter. This improvement is generally down to a combination of lower-loss electrical steels and increased conductor cross-sectional area.

The materials cost of the motor is increased by a few percent, with a typical 20% premium on selling price and the payback period for the customer can be as little as six months for a continuously loaded motor. It is estimated (De Keulenaer et al. 2004) that adoption of high-efficiency electric motors within existing systems alone would save the UK 3 billion kWh per annum.

The EU introduced the efficiency bands in the mid-1990s but, unlike the USA, which used legislation, a voluntary agreement between all of the motor manufacturers in the EU was produced, covering all two- and four-pole induction motors rated between 1 kW and 90 kW and dividing motor efficiencies into three bands.

It was expected that class III (ie lowest band) would be removed by 2002 so that all motors sold in the EU would be in the improved efficiency bands I and II. However, this does not seem to have happened. Clearly, there is an urgent need to review the position. A recently published briefing note from Defra's Market Transformation Programme (Department for Environment, Food and Rural Affairs 2006) recommends that the existing scheme is extended to cover a wider range of motor ratings. It also proposes more accurate testing procedures in order to label motors with higher efficiencies than the current class I level.

3.3 Power electronic converters

Power electronic converters are used to supply a variable frequency supply to an AC motor, thereby enabling variable speed operation. Power converters have conduction and switching losses in the power devices, losses in passive components and auxiliary cooling systems.

The loss is a function of device type, switching frequency, voltage and current level, but for industrial systems the converter has a typical full load efficiency, which rises with power rating from around 80% below 1 kW to over 97% at 150 kW (Rooks and Wallace 2004). Efficiency levels are rising as newer, low-loss, faster-switching devices emerge.

3.4 Variable-speed drives

For the purposes of this paper, an electric drive will be classified as the combination of a power electronic converter, electrical machine and electronic controller. The EU-funded SAVE II Programme (de Almeida et al. 2005) has identified large-scale application of variable-speed drives as the motor systems technology having the most significant energy savings potential. Savings within the electrical drive system alone are projected to be 6 billion kWh per annum in the UK (de Almeida et al. 2005).

Variable-speed drives have been adopted as standard within process control applications, where their variable speed gives greater functionality and is often essential for the application.

However, for the bulk of applications, a fixed-speed drive can be employed and involves a lower initial capital cost, but generally with much lower system efficiency.

3.5 Complete system

3.5.1 Industrial

The greatest potential for fuel savings are in closed-loop fluid-pumping applications (pumps, compressors, fans) with variable flow requirements (de Almeida et al. 2005). Pumps and fans of this type are often run well below their rated power level, in which case fixed-speed machines are run in an 'on/off' manner (as in the operation of a pump in a central heating system). However, the power requirement is related to the cube of the flow, so that running a pump continuously at half speed will produce the same flow as one at full speed for one half of the time, but will only require one-quarter of the energy. In (de Almeida et al. 2005), the following typical energy savings will result from replacing fixed-speed machines with variable-speed drives:

- fans : 25–30%
- compressors : 15–20%
- lifts : up to 81% when regenerative braking is included.

The efficiency improvements within the driven load (i.e. pump, fan etc.) are expected to save the UK 15 billion kWh per annum which, when combined with the motor and drive efficiency gains, amount to a total annual saving of 24 billion kWh.

3.5.2 Household

There have been extensive studies of the household sector, both in the USA (Kubo et al. 2001; Little 1999) and the EU SAVE II Project 2001). In Europe, the electricity consumption of a central heating pump is up to 600 kWh per annum, which is comparable to the complete lighting system of a household, or that of a fridge-freezer. Through adoption of efficiency standards and technical measures such as speed control, more efficient motors and seasonal switches, it is predicted that energy requirements could be reduced by more than a factor of three by 2020.

Japan is leading many aspects of innovation in motors and drives for household applications. In Morimoto et al. (2002), there is a focus on refrigeration and air-conditioning systems, which comprise over 40% of Japan's electric power consumption. By moving from induction machines to permanent magnet synchronous machines, a reduction in motor loss of over 60% is reported. This improvement is due to a combination of innovative construction techniques and the use of power electronic converters, which have made it possible to use the more efficient permanent magnet machine, and is in addition to the large gains a variable speed system produces.

3.5.3 Transport

Electric motors and drives are becoming increasingly dominant in the following modes of transport:

- **sea**: electric ship propulsion of military vessels, ferries and cruise liners is now commonplace, with the ships engine driving a generator, which in turn feeds propeller motors. The propeller can now be pod-mounted and hydrodynamic efficiency improved, resulting in system gains of up to 15% (http://www.shiptechnology.com/contractors/propulsion/abb/).

- **air**: in the 'more electric' aircraft, hydraulic and mechanical systems are being replaced with electrical alternatives, along with the introduction of electric climate control. Direct energy savings result from more efficient pumping systems, and indirect savings in fuel due to reduced aircraft mass.

- **road**: hybrid electric vehicles are able to supply fuel economy advantages over conventional vehicle drive trains (Williamson et al. 2006). For example, the Toyota Prius achieves 65.7 mpg on a Department of Transport combined driving cycle test. Both this and the Honda Insight use high-efficiency permanent magnet drives, which represent the current state of the science in high-efficiency drives.

- **rail**: most new rail systems are electrically driven, with induction motor drives. Efficiency of the drive is high, but could be further increased with permanent magnet drives. Magnetic levitation can be used to reduce drag losses and increase speed, but involves very high capital investment.

3.6 Market barriers

By far the largest barrier is one of initial capital cost. Within the industrial sector, the majority of motor and drive purchases are made by the original equipment manufacturer (OEM) and not by the end user. The OEM is concerned predominantly with selling cost, rather than lifetime cost and so has little motivation to improve efficiency.

When replacing an industrial fixed-speed motor with a variable-speed drive, the initial capital cost may be larger by a factor of three or more. The cost per kW of power reduces with power rating (de Almeida et al. 2005) until around 70 kW, above which it is relatively constant.

Household applications are particularly cost-sensitive, but brushless drives are beginning to penetrate the market, such as an LG direct-drive washing machine (Cho et al. 2004) and a Dyson vacuum cleaner (currently available only in Japan) (*Drives and Controls* 2004). Interestingly, these products are marketed more for their increased functionality, rather than their higher efficiency. Within the industrial sector, there is still a need to inform and educate the end user.

There is still a widely held belief that, by purchasing a motor rated higher than the application demands, the motor will last longer and be more reliable. In practice an over-rated motor tends to have higher iron loss, magnetising loss and friction, which will substantially reduce the efficiency. There is a strong analogy with cars of large engine size: their fuel consumption is almost always inferior to the lower-powered alternatives.

4. Future advances to 2050 and beyond

The function of an electrical drive is to convert electrical energy to mechanical energy and vice versa. This is currently achieved almost exclusively via a magnetic field. The first question to ask is 'Are there any new processes of energy conversion that may replace this in the next century?' The answer to this is simple: none are known of at the time of writing. Competing systems, such as electric fields are several orders of magnitude less power-dense or, in the case of ultrasonic motors, very inefficient. So, unless there is a truly major breakthrough, electric motors will continue to use the same basic concepts for the foreseeable future.

4.1 Key challenges

It is clear that the key challenges to increase efficiency lie in four areas:

a) Increase the adoption of variable-speed, high-efficiency systems, with a revision of efficiency bands and possibly legislation replacing voluntary agreements.

b) Extend the application areas of variable-speed drives through reduction of power electronic and control costs.

c) Integrate design of the drive and the driven load to maximise system efficiency.

d) Increase the efficiency of the electrical drive.

4.1.1 Extension of application areas

The main barrier to further market penetration is capital cost, which is dominated by the power electronic cost in the <100 kW range. Reliability is also a concern for some applications. Unlike electrical machines, which are dominated by material cost, power electronic systems are a much less mature technology, which is dominated by processing and packaging costs. Hence, with advances in these areas, the cost of power electronic converters will continue to fall substantially.

By 2050, it is possible that power electronic converters are substantially cheaper and than the machines they drive and are also highly efficient. Once this happens, a high proportion of line-connected electrical machines could be replaced by variable-speed

drives, in which the average user has no awareness (or indeed interest) in the contents of the system, only its flexibility and functionality. Energy savings will occur in traditional fan, pump and compressor applications, while entirely new markets emerge. Penetration into the consumer market will replace commutator machines, which generally operate at around 50% efficiency, with brushless permanent magnet drives of 80–90% efficiency and high functionality.

Perhaps the largest new market will be in automotive drive trains, initially in hybrid vehicles and later in fuel-cell or battery-powered vehicles. CO_2 emissions from a fuel-cell-driven vehicle are very low, but production of the fuel itself may be an inefficient process. Efficiency of the electric drive train is increased by operating at higher voltage levels than the 42 V system proposed by manufacturers. It should be noted that there is a trend to increase this voltage for hybrid vehicles to improve efficiency, recognising that safety issues also have to be addressed.

4.1.2 Integrated system design

Blaabjerg et al (2005) state how, within power electronics, semiconductor devices have hitherto been the main technology drivers; circuit topologies have stagnated, while performance, control and system integration has become the main challenge for the future.

A simple example of the need for integrated system design may be found in a pump. Most industrial pumps are designed for 1500 revs per minute, because that is the speed of the line-connected motor. If a variable-speed drive is employed, there is complete freedom to choose any speed up to >100,000 revs/minute. As the speed changes, different pump technologies can be chosen and the size of the system can be drastically reduced (*Drives and Controls* 2004). The torque from the electric motor is reduced and so loadings and electromagnetic losses can be reduced. The motor and power electronics can be integrated into the impeller, with sophisticated control systems ensuring maximum efficiency.

Even in 2006, very sophisticated programmable controllers can be purchased for a few pence. It is clear that the level of 'intelligence' within the drive will rise dramatically and that there will consequently be a huge increase in the functionality and controllability of even the most basic of products.

As higher-temperature power electronics become possible, the power electronics will become embedded in hostile environments, such as internal combustion or jet engines. This will allow electrical actuation and significant efficiency improvements in our major CO_2 producing systems.

4.1.3 Drive efficiency

The key to improve motor efficiency lies in new materials and construction methods.

Winding loss is reduced by increasing the conductivity of the winding. In the case of induction machines, recent advances in production methods are starting to allow the replacement of aluminium rotor cages with copper (Kimmich et al. 2005), decreasing machine losses by around 8–10%. Copper is already used for stator windings and is unlikely to be replaced by a more conductive material at room temperature.

Super conducting electrical machines have been researched for over 30 years, but with the advent of high-temperature superconductors, they are now close to introduction (Kalsi et al. 2004; Singh et al. 1999), both as generators and in ship propulsion systems. Super conductors have hitherto been considered only suitable for DC current and are therefore used as a field winding producing a very high flux density. Air-gap windings are employed, with an ironless stator, thereby also eliminating iron loss.

However, substantial eddy currents are induced in the AC windings because they sit in the full magnetic field. Losses in very large generators can be reduced by up to 50% and the additional energy requirement of the cryogenic cooling system is relatively low. The generator

efficiency may therefore rise from 98% to over 99%, but perhaps more importantly the generator is much smaller, which reduces the very large civil engineering cost associated with a power station.

The superconducting properties of magnesium diboride were discovered in 2001 (Nagamatsu et al. 2001). This material typically operates at 24–30°K, placing it between conventional and high-temperature superconductors. It is much cheaper to produce and easier to form into wires than other superconductors (Das 2002; Musenich 2004; Fang et al. 2005), and is being developed for AC applications. If both technical and financial criteria are met, it may have a role in future, high-efficiency electrical machines.

Eddy current losses in the soft iron material of a machine's core can be reduced by either increasing the resistivity of the core material or reducing the amount of flux that eddy currents can enclose. The former is achieved by the introduction of up to 6% silicon into the lamination material, which also reduces the coercivity and hence hysteresis loss.

There will certainly be further incremental improvements in this area. Amorphous iron (Johnson et al. 1981) reduces the thickness of the laminations and therefore the eddy current loss. Because of the crystal structure resulting from very rapid cooling, the hysteresis loss is also exceptionally low. However, the material is both expensive to produce and limited in flux density. Soft magnetic composites (Hultman and Jack 2003) replace the laminations with 100 ìm diameter iron particles which are pressed together.

This material has very low eddy current loss, but current products have greater hysteresis loss, so iron loss is only reduced at very high frequency. Soft magnetic composites have, however, been shown to offer significant efficiency gains because of their three-dimensional shaping properties.

New tooth shapes are possible, with much shorter winding lengths, thereby reducing winding loss (Jack et al. 2000). Future soft magnetic composites will incorporate special high-temperature powder coatings, which will lower hysteresis loss and make the material more attractive for energy efficient systems.

Electromagnetic design tools have advanced greatly with application of the finite element method. However, further advances will continue to develop.

Greater understanding of stray loss mechanisms is required at the design stage in larger machines. Improved understanding and modelling of iron loss mechanisms within the machine are also needed to replace the empirical scaling that continues to be adopted by manufacturers today. Eddy current loss mechanisms in high-speed machines will be addressed and new machine topologies will continue to emerge.

In most AC electrical machines, the windings have to supply two components of current – one to produce the torque and another magnetising component to produce the magnetic field. When the field is produced by a permanent magnet, the winding losses are substantially reduced and so, providing full magnetic flux is required under all operating conditions, permanent magnet machines are substantially more efficient than other AC machines.

In the last 20 years, the cost of rare-earth permanent magnet material has dropped very dramatically, and the volume of production (mainly from China) has risen exponentially.

The percentage of electrical machines that employ high-performance permanent magnets has consequently risen sharply. Very large permanent magnet machines are now being developed for propulsion (Parker and Hodge 1998) and generation purposes (Veersteegh 2004), and this will form a substantial part of the market in the next few decades.

For many fan- and pump-type loads, where field weakening is not required, it may soon become cost-effective to replace induction machines with permanent magnet machines in the general drives market and substantial efficiency gains will result. Of course, this assumes that the supply of raw materials can cope with demand and that costs continue to fall as expected.

Power electronic converters are a less mature product than electrical machines and should therefore see larger efficiency gains over the next 50 years. The conduction and switching loss in silicon-based power electronic devices will reduce, but not by orders of magnitude.

Silicon carbide, gallium nitride and diamond offer gains in this area, along with higher-temperature operation, but all semiconductors have a bulk resistance and will therefore have significant conduction drops. Interestingly, the flow of charge through a vacuum, as employed in old valve technology, overcomes this problem.

It is possible that, if this process could be successfully miniaturised, such techniques may produce very low-loss power electronics in the distant future. It has also been postulated that micro-electromechanical devices (MEMs) could have a role to play by effectively miniaturising the mechanical switch. However, these possibilities are purely speculative and the likelihood of this advance occurring must be rated low.

Power electronic converters need passive energy storage devices in the form of capacitors and inductors. The size, cost, reliability and efficiency of these devices can all be problematical, and in due course may dominate the power electronic converter performance. There have been some major gains in this area, but there is a need for further development.

Packaging of the converter remains a major challenge for the future. While signal-level electronics moved away from single discrete devices over 30 years ago, this has not yet been the case with power electronics. Integration of the power and control electronics into a single hybrid or even chip will become commonplace.

Further integration of the passive components remains a longer-term aim. Although there have been a number of attempts at limited integration with the motor, these have been hampered by thermal issues, since the motor can run hotter than the electronics. Advances in high-temperature semiconductors, including silicon carbide devices, may overcome this problem.

Integrated design can reduce lead length, and hence reduce parasitic inductance and capacitance effects. This in turn permits higher switching speeds, lower losses, and smaller passive components. Developments of this kind in switched power supplies are somewhat in advance of variable-speed drives, but many of the same advantages can be encompassed by new, ultra-high-speed electrical machines.

4.2 Key Engineering and Scientific Advances

The following key advances are required:

4.2.1 Electrical Machines

- New soft magnetic materials giving lower iron loss at low cost.
- Low-cost, high-temperature, high-energy magnets.
- High-temperature insulation and magnet systems (>400°C).
- New construction methods, including segmented stators, cast copper rotors, where appropriate.
- Bearing systems for ultra-high-speed operation.
- Reliable high-temperature superconducting designs at moderate cost.
- Improved design tools.

These advances will happen, though perhaps on a continuous incremental basis.

4.2.2 Power electronics and control

- Cost Reduction.
- New devices, materials and technology to increased switching speeds and reduced conduction drops.
- Increased integration.
- Reduced size of passive components.

Significant advances will occur. There is a significant possibility of technology breakthroughs causing fundamental advances in power electronic devices and passive components.

4.2.3 Integrated systems

- New fan, pump, compressor etc. designs for maximum efficiency where there is complete freedom of speed.
- Intelligent control methods.

5. CONCLUSION

By adopting known, proven concepts, it is possible to dramatically increase the efficiency of systems driven by electrical machines and reduce total electricity consumption by over 7%. There is a trend for increasing efficiency within the electrical machine itself, but the greatest gains are at system level when the machine is combined with a power electronic converter to create a variable-speed drive.

The main barriers to this lie in the initial cost of a variable-speed drive, even though in many cases the payback period is short. Future advances in technology will reduce the capital cost of the drive, and so existing markets will grow and new markets open up. In the future, electric drives will become integral to the propulsion of road transport vehicles, so the need for maximising their efficiency will become even more pressing than it is today.

TRAINING CALENDAR OF IRIEEN FOR 2008-2009 as on 26.02.2008

COURSE NUMBER	COURSE TITLE	DURATION			COURSE DIRECTOR	CATEGORY
		WEEKS	FROM	TO		
IRIEEN20	19TH IRIEEN BATCH OF IRSEE PROBATIONERS				SPE	IRSEE PROB
IRIEEN21	20TH IRIEEN BATCH OF IRSEE PROBATIONERS				SPE	IRSEE PROB
IRIEEN22	21TH IRIEEN BATCH OF IRSEE PROBATIONERS				SPE	IRSEE PROB
IRIEEN23	22ND IRIEEN BATCH OF IRSEE PROBATIONERS				SPE	IRSEE PROB
IC1	INTEGRATED COURSE	10	2-Jun-08	8-Aug-08	SPG	GR.B. AEE/DEE
IC2	INTEGRATED COURSE	10	29-Sep-08	5-Dec-08	SPG	GR.B. AEE/DEE
IC3	INTEGRATED COURSE	10	5-Jan-09	13-Mar-09	SPG	GR.B. AEE/DEE
SPDP1	SR.PROFESSIONAL DEVELOPMENT COURSE	8	21-Apr-08	13-Jun-08	SPT	JAG/SG
SPDP2	SR.PROFESSIONAL DEVELOPMENT COURSE	8	30-Jun-08	22-Aug-08	SPT	JAG/SG
SPDP3	SR.PROFESSIONAL DEVELOPMENT COURSE	8	1-Sep-08	24-Oct-08	SPT	JAG/SG
SPDP4	SR.PROFESSIONAL DEVELOPMENT COURSE	8	24-Nov-08	16-Jan-09	SPT	JAG/SG
AC1	AMELIORATION FOR SAG OFFICERS		31-Mar-08	23-May-08	SPA	SAG
AC2	AMELIORATION FOR SAG OFFICERS	8	26-May-08	18-Jul-07	SPA	SAG
AC3	AMELIORATION FOR SAG OFFICERS	8	21-Jul-08	12-Sep-08	SPA	SAG
AC4	AMELIORATION FOR SAG OFFICERS	8	15-Sep-08	7-Nov-08	SPA	SAG
AC5	AMELIORATION FOR SAG OFFICERS	8	10-Nov-08	2-Jan-09	SPA	SAG
AC6	AMELIORATION FOR SAG OFFICERS	8	12-Jan-09	6-Mar-09	SPA	SAG
AUDIT1	ENERGY AUDIT	2	7-Apr-08	18-Apr-08	PL	JS/SS/JAG/SG
AUDIT2	ENERGY AUDIT	2	2-Jun-08	13-Jun-08	PL	JS/SS/JAG/SG
AUDIT3	ENERGY AUDIT	2	28-Jul-08	8-Aug-08	PL	JS/SS/JAG/SG
AUDIT4	ENERGY AUDIT	2	22-Sep-08	3-Oct-08	PL	JS/SS/JAG/SG
AUDIT5	ENERGY AUDIT	2	17-Nov-08	28-Nov-08	PL	JS/SS/JAG/SG
AUDIT6	ENERGY AUDIT	2	19-Jan-09	30-Jan-09	PL	JS/SS/JAG/SG
TRS1	SPL. COURSE ON TRS/TRO	2	19-May-08	30-May-08	AP	JS/SS
TRS2	SPL. COURSE ON TRS/TRO	2	25-Aug-08	5-Sep-08	AP	JS/SS
TRS3	SPL. COURSE ON TRS/TRO	2	17-Nov-08	28-Nov-08	AP	JS/SS
TRS4	SPL. COURSE ON TRS/TRO	2	2-Feb-09	13-Feb-09	AP	JS/SS
TLAC1	SPL. COURSE ON TL&AC	2	16-Jun-08	27-Jun-08	SPE	JS/SS
TLAC2	SPL. COURSE ON TL&AC	2	11-Aug-08	22-Aug-08	SPE	JS/SS
TLAC3	SPL. COURSE ON TL&AC	2	3-Nov-08	14-Nov-08	SPE	JS/SS
TLAC4	SPL. COURSE ON TL&AC	2	12-Jan-09	23-Jan-09	SPE	JS/SS
TRD1	SPL. COURSE ON TRD	2	31-Mar-08	11-Apr-08	PL	JS/SS
TRD2	SPL. COURSE ON TRD	2	30-Jun-08	11-Jul-08	PL	JS/SS
TRD3	SPL. COURSE ON TRD	2	13-Oct-08	24-Oct-08	PL	JS/SS
TRD4	SPL. COURSE ON TRD	2	9-Mar-09	20-Mar-09	PL	JS/SS
EMU1	SPL. COURSE ON EMU/MEMU	2	21-Apr-08	2-May-08	AP	JS/SS
EMU2	SPL. COURSE ON EMU/MEMU	2	3-Nov-08	14-Nov-08	AP	JS/SS
MED1	MEDITATION	2	7-May-08	18-May-08	LC	OFFICERS OF ALL DEPARTMENTS
MED2	MEDITATION	2	15-Dec-08	26-Dec-08	LC	
COMP1	SPL. COURSE ON COMPUTERS	2	9-Feb-09	20-Feb-09	PC	OFFICERS OF ALL DEPARTMENTS
ELECT1	SPL. COURSE ON ELECTRONICS	3	11-Aug-08	29-Aug-08	SPG	JS/SS
ELECT2	SPL. COURSE ON ELECTRONICS	3	2-Feb-09	20-Feb-09	SPG	JS/SS
LHB1	MAINTENANCE OF LHB COACHES	1	28-Apr-08	2-May-08	SPT	JS/SS/JAG/SG
LHB2	MAINTENANCE OF LHB COACHES	1	1-Dec-08	5-Dec-08	SPT	JS/SS/JAG/SG
TOT1	TRAINING OF TRAINERS (At IRIEEN)	1	2-Jun-08	6-Jun-08	LC	Gazetted Principal/Vice Principal
TOT2	TRAINING OF TRAINERS(AT Thakurli)	1	2-Feb-09	6-Feb-09	LC	Non- Gazetted Instructors
LAW1	SPL. COURSE ON LAW	1	28-Jul-08	1-Aug-08	PC	JS/SS/JAG/SG
CONTRACT1	CONTRACTS & ARBITRATION	1	21-Jul-08	25-Jul-08	SPE	JS/SS/JAG/SG
AM1	ACCIDENT MANAGEMENT	1	25-Aug-08	29-Aug-08	SPA	JS/SS/JAG/SG
PD1	PERSONALITY DEVELOPMENT	1	22-Sep-08	26-Sep-08	SPT	JS/SS/JAG/SG
SJ1	SPL. COURSE FOR 1982 BATCH OFFICERS	3 DAYS	7-Jan-09	9-Jan-09	SPA	SAG
MS1	MATERIAL SCIENCE	1	23-Feb-09	27-Feb-09	LC	JS/SS/JAG/SG
REF1	REFRESHER COURSE FOR IRSEE OFFICERS	1	23-Mar-09	27-Mar-09	SPE	JS/SS
IRSME2	ELECTRONICS COURSE FOR IRSME PROB	3	9-Jun-08	27-Jun-08	SPG	IRSME PROB
IRTS1	APPRECIATION COURSE FOR IRTS PROB	1	DATES TO BE DECIDED IN CONSULTATION WITH RESPECTIVE CTIs		PC	PROBATIONERS
IRAS1	APPRECIATION COURSE FOR IRAS PROB	1				
IRPS1	APPRECIATION COURSE FOR IRPS PROB	1				
IRSE1	APPRECIATION COURSE FOR IRSE PROB	1				
IRSSE1	APPRECIATION COURSE FOR IRSSE PROB	1				
IRSS1	APPRECIATION COURSE FOR IRSS PROB	1				
IRSME1	APPRECIATION COURSE FOR IRSME PROB	1				
SPA	SR.PROFESSOR(ADMN)	PL	PROFESSOR(LOCO)			
SPT	SR.PROFESSOR(TRD)	PC	PROFESSOR(COMPUTER)			
SPG	SR.PROFESSOR(G)	PE	PROFESSOR(ELECTRONICS)			
SPE	SR.PROFESSOR(EMU)	LC	LECTURER			
AP	ASSTT.PROFESSOR					

CALENDER OF ADDITIONAL SPECIAL COURSES PLANNED DURING 2008-09

S. N.	SUBJECT	No. of weeks	Duration (from / to)
1.	Electric Traction Operation	1	03-11-08 to 07-11-08
2.	Emerging Technologies for Metros	1	10-11-08 to 14-11-08
3.	Design of OHE	1	22-12-08 to 26-12-08
4.	Non Conventional Energy	1	22-12-08 to 26-12-08
5.	Material Testing	1	27-01-09 to 30-01-09
6.	Quality Inspection of Materials	1	02-02-09 to 06-02-09
7.	Statistical Performance of Elect. Dept.	1	02-03-09 to 06-03-09
8.	Advancements in Motive Power over Railway Systems	1	02-03-09 to 06-03-09
9.	Metallurgy for Railway Materials	1	09-03-09 to 13-03-09
10.	Lifts and Escalators	1	16-03-09 to 20-03-09
11.	Electric Lightings	1	23-03-09 to 27-03-09

DISCLAIMER

The views contained in articles published in this journal are the views of Authors and not of IRIEEN

PASSING OUT 2008











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