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# **ELECTRICAL POWER ENGINEERING**

# Modified Design of Traction Motor for Diesel Electric Locomotive

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**Abstract** — In diesel electric locomotive, the numbers of the six DC traction motors are essential because it is need to drive the axles through a reduction gear and pinion arrangement. These motors are connected in parallel connection in the main circuit. At present, the ZD110 traction motors with capacity of 2000HP and 1000HP which are manufactured by Dalian and Sifang Locomotive and Rolling Stock Works separately and exported to Myanmar Railways. But, these motors damages before having long service life. This paper intends to design the better qualitative and durative motor by studying and analyzing the present motor.

**Keywords**— Traction motor, Myanmar Railways, Diesel Electric Locomotive, reduction gear, and pinion arrangement

## I. INTRODUCTION

Traction motor is a four-pole, force-ventilated, series-wound DC traction motor, which is used for narrow-gauge diesel-electric locomotive. It has features of small size, light weight, wide speed regulating in the range of constant power, large margin of temperature rise and commutation, and good universality. Advanced manufacturing technology imported from the world and our mature experience in manufacturing have been used in manufacture processes. The magnet frame is welded with press formed steel plates, armature windings are made of Kapton file conductors and the ground insulation of armature windings uses NOMEX channel insulation. Integrative insulation structure is adopted to the coils and cores of main poles and inter pole, steel wire rebinding and VPI are applied in producing the armature.



Fig. 1 Stator frame of motor



Fig. 2 Armature core

### A. Choosing D.C Series Motor for Traction Application

The main advantages of choosing D.C Series Motor for traction application are as follows;

1) *The ratio of output power to the weight of the motor is the highest:* The field windings are connected in series and hence the field winding consists of comparatively small number of turns having fairly large copper sections. The voltage between turns is very low and consequently the insulation required is much less. The heat transfer is also high and consequently less copper is required for a given load current. The winding can be designed for higher rigidity to provide greater resistance to shock and vibrations. All these advantages result in a high power to weight ratio.

2) *The variation in torque is always greater than the corresponding variation in current:* As the field windings are connected in series with the armature, the field strength (ampere turns) is proportional to the armature current, and consequently the magnetic flux varies in proportion to that of the armature current. As the torque of the motor is proportional to the product of magnetic flux and armature current the variation in torque is always greater than the variation in the armature current.

3) *Variations in line voltage do not affect the torque:* In series motor the torque corresponding to a given load current is entirely independent of variations in line voltage. This is particularly advantageous during starting where the line voltage drops considerably due to high starting current series motors can be designed to higher ratio of field to

armature ampere turns, without having commutation difficulties inherent in other types of motors. This also results in higher power to weight ratio.

(4) *Speed of D.C motors automatically decreases as the torque increases:* This characteristic of the DC series motor is the main advantage of the series motor. This characteristics is particularly advantageous in Suburban Railway service where supply interruption are frequent, and may result in overloading in absence of this inherent characteristics.

When many motors are running in parallel in one Locomotive the current taken by each individual motor at any given speed does not vary very much than that taken by other motors. All the above advantages of the Series motor are fully utilized in Diesel Electric Locomotive.

**B. Motoring Circuit in Locomotive**

Locomotive uses AC-DC electric transmission unit. The traction alternator TA is a 3 phase synchronize traction alternator. The AC power generated by TA is provided for DC traction motor after being rectified by 3 phase bridge type main rectifier panel MRC. The number of the 6 DC traction motors counting from end 1 of the locomotive, varies from TM1 to TM6 with parallel connection in the main circuit. As shown in Fig. 1. There are 6 line contactors P1-P6 connected between MRC and traction motors to control each traction motor circuit respectively.

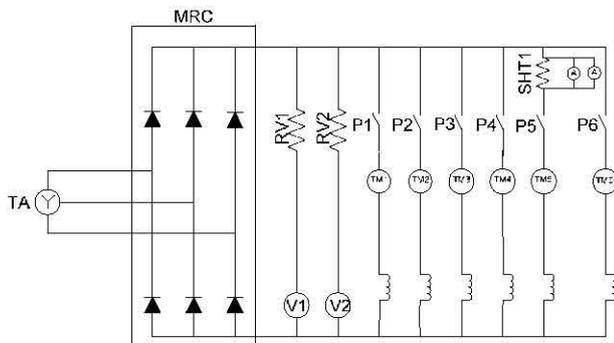


Fig. 3 Parallel connection of 6 DC traction motors in the main circuit of locomotive

**II. TRACTION MOTOR DESIGN THEORY**

**A. Equation for Armature Design (Output Equation)**

Output equation expresses the relationship between the output of the machine and the main dimension of the armature in terms of specific magnetic and electric loadings. It is essential to define the terms specific magnetic and electric loadings before the derivation of output equation.

From equation (1) the value of  $D^2L$  is obtained, now next step is separate out the value of  $D$  and  $L$ , this is achieved by making tried assumptions. Normally, the length of the armature,  $L$  may be taken approximately equal to the pole arc. The ratio of pole arc to pole pitch of a DC machine with inter pole is 0.68 to 0.7. Therefore we must mainly make well tried

assumption for the ratio of pole arc to pole pitch and the ratio of pole arc to armature length.

$$D^2L = \left( \frac{1}{c_0} \right) \frac{P_a}{N} \text{----- (1)}$$

**B. Specific Magnetic Loading**

It is defined as the ratio of total flux around the air gap to the air gap area. It is equal to the average flux density in the air gap of the machine.

$$\text{Average gap flux density, } B_{av} = \frac{P\phi}{\pi DL} \text{----- (2)}$$

- $P$  = number of poles in d.c. machine
- $\phi$  = gap flux per pole, wb
- $D$  = diameter of armature, m
- $L$  = gross length of armature, m

**C. Specific electric loading**

It is defined as the total number of ampere conductors on the armature per unit circumference of armature i.e.

$$\text{Specific electric loading, } q = \frac{I_a Z_a}{\pi D} \text{----- (3)}$$

- $I_a$  = current in armature winding
- $Z_a$  = number of conductors in each parallel path

The approximate values of specific loading based on value of air gap flux density given in Table I.

TABLE I  
APPROXIMATE VALUE OF AIR GAP FLUX DENSITY

Output kW	$B_{av}$ Tesla	Output kW	$B_{av}$ Tesla
5	0.43	500	0.66
10	0.45	1000	0.68
50	0.56	1500	0.70
100	0.6	2000	0.72
200	0.62	5000	0.74
300	0.64	10000	0.76

**D. Advantages and Disadvantages of Higher Specific Magnetic and Electric Loadings**

Advantages are

1. Reduction in the volume of the machine.
2. Reduction in the size of the machine.
3. Lower cost of the materials required.
4. Reduced weight of the machine.
5. Lower overall cost of the machine.

Disadvantages are

1. Increased iron losses
2. Larger requirement of mmf
3. Higher field copper and armature copper losses
4. Higher tooth flux density
5. Tendency of saturation of magnetic parts
6. Increased reactance voltage
7. Inferior commutation
8. Increased reactance voltage
9. Higher temperature rise due to higher losses

10. Increase noise
11. Reduction in over load capacity

### C. Output Coefficient

The approximate values of the output coefficients for different machines are as follows

1. For large machines, 4.5 to 5.5
2. For medium size machines, 3 to 4
3. For small machines, 1 to 3

### D. Choice of Number of Poles

Selection of number of poles has important bearing on the design of both magnetic and electric circuits of d.c machine. Guide lines for selection of number of poles

1. Frequency of flux reversal may be taken between 25 to 50 Hz, in order to keep iron losses within limits.
2. The current per brush arm should not exceed 400 A, in order to avoid excessive sparking.
3. The armature ampere turns per pole should not exceed the given in Table III, for avoiding inferior commutation.

### E. Main Pole

The main pole consists of magnetic pole body surrounded by field coil.

1) *Axial length:* To take into consideration, the end play and to avoid magnetic end play, The axial length of main pole is 10 to 15 mm shorter than the core length of armature length.

TABLE II  
ARMATURE AMPERE TURNS PER POLE

<b>Output kW</b>	Up to 100	100 to 500	500 to 1000	1000 to 1500	1500 to 2500
<b>Armature T/pole</b>	500	500 to 7500	7500 to 8500	8500 to 10,000	10,000 to 12500

2) *Width:* Since, the pole is to carry the main flux and leakage flux, a leakage factor of 1.2 is normally taken. Thus the flux in the main pole = 1.2  $\phi$ . Since, the main poles of the DC machine are stationary member carrying Dc flux, a higher value of flux density as 1.6 to 1.7 T ( tesla) is permitted in. Therefore, the net cross sectional area of main pole= 1.2  $\phi$ /(1.6 to 1.7) mm<sup>2</sup>. The gross cross sectional area will be net cross sectional area/ iron factor. The value of iron factor usually lies between 0.92 to 0.95. This will be the width of pole body.

3) *Height:* The height of the main pole should be such as to accommodate the field coil. Usually cylindrical field coils are used for medium and large side DC machine. These coils are so designed that their surface area dissipates the losses occurring in the coil.

### F. Commutator Design

The diameter of the commutator is taken as (0.6 to 0.7) D for medium and large machine and (0.7 to 0.8) D for small machine subject to the following considerations.

1. The conducting segments should not be less than 3 mm thick and these segments should be separated by mica separator having thickness more than 0.8 mm
2. The peripheral speed of the commutator should be less than 30 m/s.
3. Distance between adjacent brush arm spindles should be 250 to 300.

### G. Brush design

The standard sizes of brush available are shown in table 3;

TABLE III  
STANDARD SIZES OF BRUSH

Machine	Width(mm)	Height(mm)	Thickness (mm)
Small size	16	25	5,6,3,8,10
	12.5	25	5,6,3,8,10
Medium size	20	32	8,10,12.5,16
	25	40	10,12.5,16,20
Large size	32	40	10,12.5,16,20,25
	40	50	10,12.5,16,20,25, 32

### H. Efficiency

The ratio of output of the machine to its input is called the efficiency of the machine i.e.

$$\eta = \frac{\text{output}}{\text{input}} \text{-----(4)}$$

## III. DESIGN DATA SHEET OF TRACTION MOTOR

Specifications	Unit	Design Value
<i>A. Input data</i>		
Motor output	kW	235
Voltage	V	400
Speed	rpm	705
Armature current	A	650
Internal drop	V	12
Induce e.m.f	V	388
Type	-	series
<i>B. Main dimensions</i>		
Armature diameter	m	0.57
Gross Length	m	0.31
Peripheral speed	m/sec	21.4
Number of poles	-	4
Frequency of flux reversal	Hz	23.5
Pole pitch	m	0.448
Net iron length	m	0.243
Flux per pole	wb	0.0885

**C. Armature winding**

Type	-	Lap
No. armature conductor	-	416
No. slots	-	52
Conductors per slot	-	8
Current per conductor	A	162.5
Conductor area	mm <sup>2</sup>	32.5
Slot area	mm <sup>2</sup>	466.4
Resistance of winding	ohm	0.016
Weight of copper	kg	91.07
Temperature of armature	C	53.3

Cross section area	mm <sup>2</sup>	282.6
Depth of winding	cm	1.98
Resistance	ohm	0.002108
<b>K. Over all performance</b>		
Full load efficiency	%	92.36

**Specifications Unit Design Value**

**D. Field System**

Axial length of pole	m	0.295
Breadth of pole	m	0.234
Height of pole	m	0.286

**E. Magnetic circuit**

Gap flux density	Tesla	0.63
Flux density in the armature core	Tesla	1.3
Flux density in arm teeth	Tesla	2.02
Flux density in yoke	Tesla	1.2
Depth of yoke	m	0.09
Ampere turns for yoke	-	595.08
Ampere turns for armature-	-	8450

**F. Series field winding**

Turns per poles	-	13
Cross section area	mm <sup>2</sup>	130
Resistance	ohm	0.00984
Copper losses	kW	4.157

**G. Commutator**

Number of segments	C	208
Diameter	m	0.4
Length	m	0.34
Commutator losses	kW	1.654
Temperature	C	18.74

**H. Brushes**

Thickness	mm	20
Width	mm	25
Height	mm	40
Brushes per spinder	-	4

**I. Inter pole**

Axial length	m	0.1984
Height	m	0.2832
Width of inter pole shoe	m	5.4207

**J. Inter pole winding**

Ampere turns for inter pole		8682.21
Turns on each inter pole		14

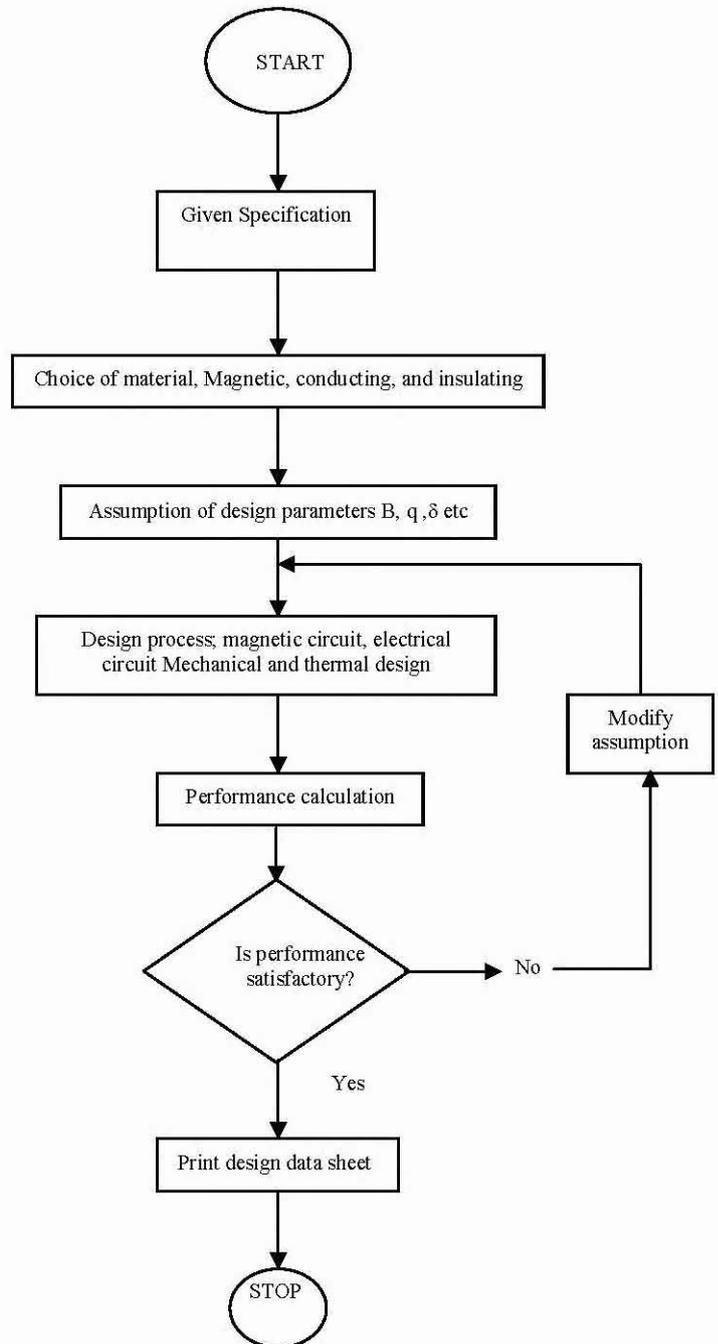


Fig. 4 Design calculation flow chart

TABLE IV  
COMPARISON DATAS BETWEEN MODIFIED AND PRESENT  
DESIGN

Specifications	Unit	Design Value	
		Old	Modified
Armature	mm	445	570
Armature	mm	445	570
Gross length	mm	260	310
Peripheral speed	m/s	16.43	21.04
Resistance of winding	ohm	0.017	0.016
Temperature rise of armature	C	70	53.3
Number of conductor	-	464	416
Number of slots	-	8	8
Gap flux density	wb	1.26	0.63
Axail length of main pole	mm	181	234
Turns per pole	kg	17	13
Brushes per spindle		2	4
Resistance of field winding	ohm	0.01	0.00984
Full load efficiency	%	87	92.3

### III. CONCLUSION

According to the above values, the efficiency of modified design value is very good or high. This design may be used till particular life duration without any damage. But this design is bigger in size than present motor.

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