# CALCULATION OF AN ELECTRIC POWERED ROAD MARKING MACHINE

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***Abstract*— This paper presents a road marking system equipped with a fully electric drive. The system is also supported with solar panels for prolonged usage time per charge. Commercial vehicles using clean energy is getting more and more important day-by-day. When it comes to urban use of vehicles, this challenge also combines with safer fuel needs. Also, most of the commercial vehicles are used at low/off-traffic hours, at night, so that low noise is another problem that should be solved. To solve the problems mentioned, using electrical drive is a useful solution. Road marking machines work at around 4 km/h and they are not allowed to go faster than 15 km/h so the speed scatter is so narrow. Constant and low speed allows use of heavier batteries like lead-acid so the system gets more affordable than the light battery using counterparts. The designed system can work continuously for 4 and a half hours without solar cells.**

***Keywords— Road Marking Machine, BLDC, Solar-Cells, Battery Electric Drive***

## I. INTRODUCTION

Internal combustion engines have been used for internal combustion engines. As researches show gasoline engines emit more than twice $CO_2$ than electrical counterparts. [1] Thus, due to today's environmental conditions more vehicles are being turned into electrical powered.

In order to not to experience a resistance in the market, an old-fashioned model structure will be modernized.

The current system was primarily designed as a diesel-powered machine. Thus, for the new system's calculations will use the old system's weight and geometrical values. While calculating, and realizing the real vehicle, some data like battery weight are estimated. After the calculation corrected, before final system design calculation.

In order to design the system with the low speed requirements brushless permanent magnet motors used because of their high efficiency and low maintenance requirements. [2],[3] Due to narrow max to min speed scatter band a fixed gear-box is added. Gear-box will decrease the speed of the motor and increase the torque output. The system will be used in parking areas and streets, the usage duration is estimated from 3 to 6 hours.

To extend the usage duration per charge solar panels added to the design. Panels will also provide emergency power.

## II. PRE-DESIGN

### *A-Pre-Design Criterion*

The vehicles pre-design values depicted below:

- Total mass of vehicle $M_{total}$=3500[kg], 2200[kg] of this is reserved for batteries, solar panels, controllers, cables etc.
- Nominal and maximum speed of the vehicle, while climbing, $v_{nominal}=4\pm1$[km/h]; $v_{max\text{-}predesign}=10$[km/h].
- Maximum angle of climb is a=9 ° (~16%)
- Air drag coefficient is $C_w=0.6$
- *Projection area of the vehicle is A=1.5x2.5[m²]*
- Rollin resistance is $f_r=0.02$ for rubber tire radius of $r_{tire}$=0.295[m]
- $\rho_l$ = 1.228 kg/m³ ; air density

### *B. Design Formulation*

By using those input power need can be calculated.

$$P_{st} = M_{total}.g.\sin\alpha.V \qquad (1)$$

Equation 1 is for calculating hill climb power in Watts.

$$P_r = f_r.M_{total}.g.V \qquad (2)$$

Equation 2 is the formulation for rolling resistance in Watts.

$$P_L = \frac{\rho_l.V^3.A.C_w}{2} \qquad (3)$$

Equation 3 will be used for calculating air drag in Watts.

## III. CALCULATION OF THE SYSTEM

In this part system's power requirements, will be calculated for the pre-design, accepted, values:

### *A. Pre-Design Power Consumption Calculation*

By using the formulations mentioned above pre-design nominal and pre-design maximum loads can be calculated,

$P_{max\text{-}predesign}$ is calculated when $v = v_{max\text{-}predesign}$

$$v_{Max\text{-}Predesign} = 10[km/h] \equiv 2.\overline{77}[m/s]$$

$$P_{st\text{-}Max\text{-}Predesign} = M_{total}.g.\sin\alpha_{Climb}.v_{max}$$

$$P_{st\text{-}Max\text{-}Predesign} = 3500.(9.80665).(\sin 9).(2.\overline{77})$$

$$\underline{P_{st\text{-}Max\text{-}Predesign} = 14914.84[W]\ \textit{Needed Max Design}\ \text{Climbing}\ \textit{Power}}$$

$$\rho_l = 1.228\ kg/m^3; A = (1.5)(2.5) = 3.75[m^2]; C_w = 0.6$$

$$P_{L\text{-}Max\text{-}Predesign} = \frac{\rho_l.v_{Max}^3.A.C_w}{2}$$

$$P_{L\text{-}Max\text{-}Predesign} = \frac{1.228.(2.\overline{77}^3).3.75.0.6}{2}$$

$$v_{Nominal-Predesign} = 4[km/h] \equiv 1.\overline{11}[m/s]$$

$$P_{st-Nominal-Predesign} = M_{total}.g.\sin\alpha_{Climb}.v_{Nominal}$$

$$P_{st-Nominal-Predesign} = 3500.(9.80665).(\sin 9)(1.\overline{11})$$

$$\underline{P_{st-Nominal-Predesign} = 5965.9[W] \leftarrow \textit{Needed}\ \text{Nom.}\textit{Design Climbing Power}}$$

$$\rho_l = 1.228\ kg/m^3; A = (1.5)(2.5) = 3.75[m^2]; C_w = 0.6$$

$$P_{L-Nominal-Predesign} = \frac{\rho_l.v_{Nominal}^3.A.C_w}{2}$$

$$P_{L-Nominal-Predesign} = \frac{1.228.(1.\overline{11}^3).3.75.0.6}{2}$$

$$\underline{P_{L-Nominal-predesign} = 1.89[W] \leftarrow \textit{Needed}\ \text{Nom.}\textit{Design Wind Power}}$$

$$P_{r-Nominal-Predesign} = f_r.M_{total}.g.v_{Nominal}$$

$$f_r = 0.02\ \textit{Tire and Road Dependent res.coef.}$$

$$P_{r-Nominal-Predesign} = (0.02)(3500)(9.80665)(1.\overline{11})$$

$$P_{r-Nominal-Predesign} = 762.7[W] \leftarrow \textit{Needed}\ \text{Nom.}\textit{Design Roll Resist.Power}$$

$$\underline{P_{L-max-predesign} = 29.61[W] \leftarrow \textit{Needed Max Design Wind Power}}$$

$$P_{r-Max-Predesign} = f_r.M_{total}.g.v_{max}$$

$$f_r = 0.02\ \textit{Tire and Road Dependent res.coef.}$$

$$P_{r-Max-Predesign} = (0.02)(3500)(9.80665)(2.\overline{77})$$

$$P_{r-Max-Predesign} = 1906.85\ [W] \leftarrow \textit{Needed Max Design Roll Resistance Power}$$

$P_{nominal\ predesign}$ is calculated when $v = v_{nominal}$

$$P_{Max-Predesign} = P_{r-Max-Predesign} + P_{L-Max-Predesign} + P_{st-Max-Predesign}$$

$$P_{Max-Predesign} = 16.8[kW]$$

$$P_{Nom.-Predesign} = P_{r-Nom.-Predesign} + P_{L-Nom.-Predesign} + P_{st-Nom.-Predesign}$$

$$P_{Nominal-Predesign} = 6.73[kW]$$

### B. *Selection of the Motor*

By summing up the pre-design calculations needed power output of the tire is Pmax-predesign is 16.8[kW] and Pnominal-predesign is 4.80[kW].

TABLE I. Motor Characteristics (Shortened)

| List No. | Motor Input | | | Motor Output | | | Eff. |
|---|---|---|---|---|---|---|---|
| | V | A | W | N.m | rpm | W | % |
| *12* | *72.04* | *84.14* | *6061* | *16.8* | *3108* | *5464* | *90* |
| *13* | *71.9* | *96.94* | *6970* | *19.77* | *3039* | *6290* | *90.3* |
| *21* | *70.55* | *210.1* | *14820* | *47.1* | *2516* | *12394* | *84* |
| 22 | 70.41 | 221.7 | 15610 | 50.5 | 2437 | 12873 | 83 |
| 23 | 70.29 | 231.7 | 16290 | 53.7 | 2343 | 13167 | 81 |
| 24 | 70.16 | 241.2 | 16930 | 56.9 | 2250 | 13407 | 79 |
| 25 | 70.07 | 247.7 | 17350 | 60 | 2144 | 13475 | 78 |
| 26 | 70.13 | 242.9 | 17030 | 62.7 | 1965 | 12904 | 76 |
| 27 | 70.19 | 237.7 | 16680 | 68.8 | 1640 | 11819 | 71 |
| 28 | 70.23 | 235.1 | 16510 | 74.8 | 1357 | 10629 | 64 |

The pre-design values only represent the power requirements for the estimated calculation values.

By this calculation, a BLDC motor with 6[kW] nominal power output can be evaluated as possible candidate. (See Table 1 motor characteristic table)

As can be seen from the Table-1 the motor can provide nominal pre-design power with 90% efficiency (Table I line 12) and maximum pre-design power with 84% efficiency (Table I line 21).

*C. Selecting The Reductor*

After selecting the motor, torque values will be checked via equation 4 , where n is revolution of the motor, P is power and T is torque.

$$T_{[Nm]} = \frac{P_{[W]} x 9.549}{n_{[rpm]}} \quad (4)$$

Calculated max and nominal torque values are calculated as follows:

TABLE II. Gearbox Characteristics

| Nominal Torque | Ratio | Output Speeds | Input Speeds | Power Pe/Pt [kW] (For Service Factor fs=1.0) Pe=Mechanical Power/Pt=Thermal Power | | | Weight |
|---|---|---|---|---|---|---|---|
| Ma[Nm] | i | n2 [rpm] | n1[rpm] | Pe [kW] | Pt [kW] | η Efficiency | [kg] |
| 57 | 7.25 | 400 | 2900 | 2.7 | 1.8 | 0.89 | 4.1 |
| 54 | 9.5 | 305 | | 2 | 1.6 | 0.87 | |
| 60 | 12 | 242 | | 1.8 | 1.3 | 0.84 | |
| 63 | 14.5 | 200 | | 1.6 | 1.2 | 0.83 | |
| 59 | 19 | 153 | | 1.2 | 1.1 | 0.82 | |
| 63 | 25 | 116 | | 0.97 | 1 | 0.8 | |
| 65 | 29 | 100 | | 0.94 | 0.76 | 0.73 | |
| 61 | 38 | 76 | | 0.68 | 0.72 | 0.71 | |
| 59 | 50 | 58 | | 0.53 | 0.64 | 0.68 | |
| 59 | 62 | 47 | | 0.45 | 0.57 | 0.64 | |
| 53 | 83 | 35 | | 0.3 | 0.59 | 0.65 | |
| 45 | 100 | 29 | | 0.26 | 0.44 | 0.54 | |

$$T_{Max-Predesign} = \frac{P_{Max-Predesign} 9.549}{n_{Max-Predesign}}$$

$$T_{Max-Predesign} = \frac{(16800)9.549}{2516}$$

$$T_{\text{Nominal}-Predesign} = \frac{P_{\text{Nominal}-Predesign} 9.549}{n_{\text{Nominal}-Predesign}}$$

$$T_{\text{Nominal}-Predesign} = \frac{(0.76)9.549}{3108}$$

$$T_{\text{Nominal}-Predesign} = 20.68[Nm]$$

$$T_{Max-Predesign} = 63.96[Nm]$$

Also, the motors lowest possible speed is around 2000[rpm] with 77% efficiency and 62[Nm] torque. Any lower speed can cause drastically lower efficiency so this speed will be accepted as the lowest speed.

In order to provide needed speed a gear box will be used. The required nominal velocity $v_{nominal}$ (4 [km/h]) will be used to calculate the required reduction.

The speed can be calculated by using angular velocity $\omega$ with equation 5 and velocity v via equations 6.

$$\omega_{[rad/s]} = \frac{2 * \pi * rpm}{60} \quad (5)$$

$$v = r * \omega \quad (6)$$

Converted motor speed is for Low Speed (2000[rpm]) 209.44[rad/s] and for High Speed (3175[rpm]) is 332.48[rad/s]. The vehicles angular velocity with the tire radius of 0.295 [m] (10" tire) is $\omega_{max\_predesign}$ is 0.44[rad/s] and $\omega_{nominal}$ is 0.18 [rad/s]. Since nominal speed is more important for the design criteria the gearbox should be calculated for nominal speed. For 2000rpm motor speed 1/52 gear ratio is needed to reach 4[km/h] speed. (Please see the Table 2 for selected gearbox characteristics.)

This redactor can provide 1/50 ratio with 68% efficiency and that leads to 4.44 [km/h] at 2000rpm and 7[km/h] at 3175 [rpm].

## IV. Recalculation of The Power Consumption For The Final Design Values

*A. Recalculation of The Power Requirement*

By using the new speed values, following values would be calculated. During climbing max speed can be lowered to 5[km/h] , P max will be calculated for that value. Pnominal will be calculated for flat road with 4[kmh].

$P_{max}$=8415[W] ($P_{st}$=7457[W] Climbing; Resistance $P_L$=3.7 [W] Wind Resistance; $P_r$=762,7[W] Roll Resistance) ; $P_{nominal}$=764.6[W] (PL=10.43[W] Wind Resistance; Pr=961.87[W] Roll Resistance)

The calculated values represent wheel output requirements so they should be corrected via efficiency in order to calculate the power usage. By using the efficiency values from the Table 1 and 2 also by adding another 90% general efficiency regarding cable, connection and other loses, the following chart can be acquired.

TABLE III. Motor Output Power and Efficiencies

| | Wheel Power Output | | Mech. Eff. | Elec. Eff. | Other Losses |
|---|---|---|---|---|---|
| Pt max | 8421.00 | Watt | 0.68 | 0.90 | 0.90 |
| P nominal | 764 | Watt | 0.68 | 0.77 | 0.90 |

Additionally, the vehicle needs another electrical motor to run the painting equipment.That is 0.25[kW] for Hydraulic Oil Radiator, 6[kW] for Road Marking Paint Pumps, and 3 [kw] for Air Compressor for Paint Valves.

So, maximum additional power requirement is 9.25[kW].

The nominal consumption of the painting equipment is empirically determined and is approximately equals to half of the max usage, 4.63[kW].

As can be seen from the Table I list no. 13, the motor specifications are adequate. Thus, the system would be equipped with two identical motors. The painting equipment needs 3000[rpm], therefore, the second motor will directly drive the painting system. The second motor will consume 5.12[kW] due to 90.3% efficiency.

## V. Calculation of the Battery Packs and Solar Pannels

### A. *Calculation of The Battery Packs*

Motor output is calculated by only considering non-electrical efficiency values, mechanical efficiency and other losses, as $P_{max}$= 13.7[kW] and $P_{min}$=1.25[kW].

Noting that, $P_{max}$ is higher than the motor capacity, the max speed while climbing a hill with 16% slope will be reduced to 5 [km/h].

For the current calculations, actual consumption of the motor is added up to 15.7[kW] for $P_{max}$ and 1.6[kW] for P nominal by using the efficiency values 0.90% and 0.77%, respectively.

To calculate the battery capacity for moving the vehicle 20% $P_{max}$ and 80% $P_{nominal}$ work load estimated, the equivalent of this is 4353.5 [Watts], and 5120[W] will be consumed by painting systems. Motor voltage rate is 72[V] and 4-hour work duration is expected, so by calculating the ampere usage per hour is calculated.

The lead acid batteries cannot be used due to their lack of deep-cycle capabilities. Deep-Cycle, traction batteries, used because they can be used up to 80% of their capacities. The calculated data can be seen on the following chart.

TABLE IV. Battery Packs

| Selected Battery | | | |
|---|---|---|---|
| V | Ah | Weight of a Set ( Cabels not included) [kgf] | Work Duration [h] (up to 80% capacity) |
| 80 | 600 | 1679 | 4.05 |

### B. *Calculation of Solar Pannels*

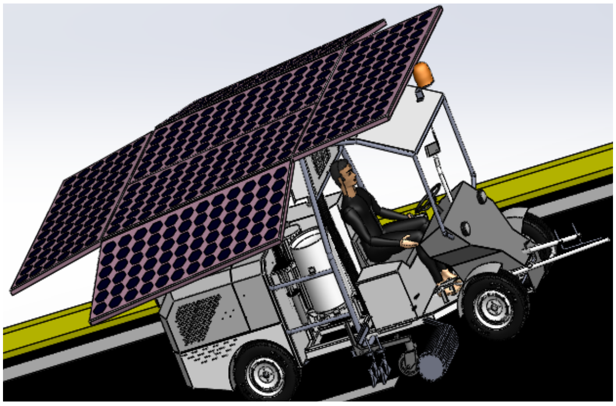
The vehicle provides enough area for 6 solar panels each with 300[w] capacity. Providing 90% efficiency while charging the batteries with the solar panels, the panels can charge the system 0.17 hours of run time (on corrected load) and extends 4 hours of service time up to 4.7 hours in daytime usage.

The Designed vehicle's model is depicted on Picture I. The top of the vehicle is covered with the solar panels, the total panel weight is 174kg (29kg each). The panels will be supported with MPPTs. The estimated reserve weight of 2200 kg is more than needed, but in order to compensate possible extra weight of the cables and fittings this value has not been reduced in the calculations.

## VI. Conclusion

In this research, a diesel-powered road marking machine upgraded into today's requirements. The thrust is provided by a single 6kW BLDC electrical motor. The torque and speed adjustment is done through a fixed gear with dual shaft output.

PICTURE I. 3D Model View of ALT-180® Plug-in Electric Road Marking Machine



The new designed system has all the capabilities of the previous system. The painting equipments are also being powered by an electrical motor. Two motor are identical.

By using the identical motors and motor drivers provide easier maintenance and user training. That would allow the diesel-type operators to be instructed faster.

The electrical motor has fewer moving parts, need for periodic and non-periodic maintenance is fewer than that of diesel engines. [19], [20]

The designed system can provide requested speed and maneuverability values. It has solar support, that can be used in emergency as-well-as in daily use. System's batteries can be found anywhere easily and can be changed without a special training but the standard traction battery changing procedure.

The new system has lower noise levels than diesel versions. The system has less maintenance requirements and less moving parts. Lowering the number of the moving parts leads to higher efficiency and longer product life. The road marker can climb a 15% hill slope with 5 [km/h] speed and can work for 4 hours without being recharged at night time.

The battery pack can be changed by a fork-lift. The current system is designed as first type and future models will be equipped with ion batteries that are lighter and environmental friendly if disposed.

The designed system is not equipped with a differential due to low speed (4 [km/h]). Hub motors are not found to be suitable with this system's high torque low speed requirements so a BLDC disk motor is selected with a gear box that provides dual shaft outputs for each of the rear tires.

The designed system can provide lower noise and carbon pollution thus will increase urban application range to more silent and clean areas.

For example, working at night time hospital parking lots and universities at daytime.

To sum up, this paper the conversation of a diesel-powered road marking machine to electric powered type has been calculated. Also, practical applications considered and analysed.

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