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# Optimization of traction unit for low-cost automated guided vehicle

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**Abstract.** AGV system already known today is commonplace in any large-scale production, warehousing or supply process logistics. System is not only increasing process flexibility but also the quality of products and services. They are unattended vehicles designed for towing, guiding and carrying various types of cargo using peripheral devices designed for these vehicles. The paper describes the design of the traction unit of the automated guided vehicle (AGV). The main goal of this design is optimization of traction unit for a low-cost version of commercial AGV and thereby reducing overall costs of equipment. The traction unit must be designed so that the equipment that uses such a type of traction unit meets customer requirements.

## 1. Introduction

**Industry 4.0** is a fundamental change not only in the industrial but also in the private sphere of each of us. Industry 4.0 is a technological (digital) revolution of the present, bringing many changes in work, communication and the way we live. This revolution also concerns automated systems, where it is raising awareness among, for example, individual members of the production process (device-to-device communication). Therefore, many companies are transforming more and more into so-called ‘Smart Factory’. It is a wide range of production, which main goal is optimizing the production concept and thereby creating a flexible and configurable company.

## 2. Smart factory with cellular manufacturing

Changes in production and also in production logistics depend mainly on customer requirements. This type of production is driven by the customer and is necessary to adapt production to the product. Cellular production is a form of standard serial production that distributes work into separate teams known as cells that can be divided into three categories [1, 2]:

**Production cells** - cells (workstations) that contain production facilities (machining, casting, forging, welding...).

**Assembly Cells** - standard cells for mounting separate units into a unit.

**Process cells** - in other words, technological cells determined by technological processes of production (surface treatment, painting, heat treatment).

In general, cellular production has several advantages, such as:

- shortening production time and consequently shortening the time to market;
- reducing the cost of transforming the production line and the like.

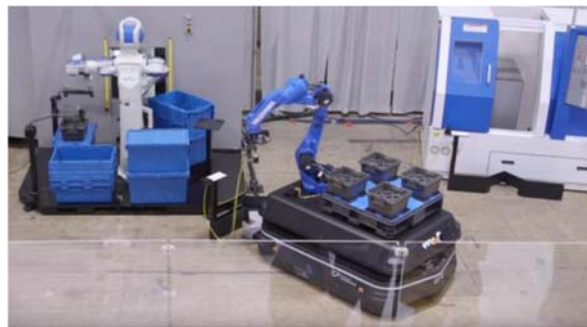


There are also several drawbacks to cellular production, for example:

- high technical requirements for production preparation;
- high input costs;
- need for higher operator qualifications.

Many automated logistics systems of various kinds have been implemented in production processes at present. These systems are providing internal logistics within the manufacturing processes of companies. Such a combination of an automated logistics system and cellular production brings many savings not only within material flows, warehouse or handling operations, but also within the organization of opaque manufacturing processes, resulting in several major cellular production parameters associated with automated logistics and that [1, 2, 10]:

- increased flexibility;
- reduction of production times;
- shortening transport distances;
- direct material flow...



**Figure 1.** Example AGV cobot cooperating on workplace.

In the preceding figure 1, a simplified example of a cellular production connection (CNC machine and sorting position) and an automatic logistic system (cobot handling) is shown, which as a whole form a solution for performing multiple handling operations and logistics tasks throughout the manufacturing process [8].

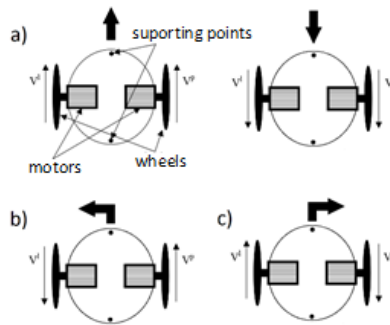
### 3. Modular platform

Different levels of automation, resulting from customer needs can be covered by AGV modular solution. At present, it is a requirement from customers, create more complex solutions by combining cellular production and an AGV system. These solutions providing the possibility of replacing physical operator with a fully automated (autonomous) platform of production cell. In many cases it will be able create more friendly working conditions for people [5, 6, 13].

CEIT, a.s., implements the development of equipment achieving the required parameters. One of these devices is the prototype platform being developed for handling and inter-operational purposes within individual cell manufacturing sections. This type of AGV platform will represent the middle class of autonomous vehicles and is designed to implement for inter-cell operations. It is a full-fledged autonomous guided vehicle with mark **AGV 400LC-F**, whose design has been developed as the basis of a modular platform, to which many peripherals (modular superstructures) can be attached. The shape and function of the peripherals depends on the cell production sections (cells). This modular platform can provide sections exchange during operation or directly supply or serve individual production cells.

#### 4. AGV 400LC-F

This type of AGV can be described as a competitive modular platform, where is important to maintain the compatibility of the chassis with individual peripheral devices. Typically, when designing an autonomous logistics tractor, the first problem is to design a base frame (chassis) and determine the appropriate number and type of wheels for the traction unit and wheels for the carrier part. The device is based on a 6-wheel chassis with omnidirectional wheels oriented on the front and the rear section of the chassis and a traction unit (the axle) in the middle of the chassis so that the turning radius of the device is zero. The following figure 2 shows principle of differential steering of wheels.



**Figure 2.** Principle of differential steering of wheels.

This orientation of the traction unit also serves as the equivalent of a mechanical differential. Differential type of drive is the easiest and most used type of mobile robot chassis used mainly for small and low-cost robots working indoor. It is independent control of traction wheels driven most often by DC electromotors with encoders or stepper motors.

The supporting points of chassis are usually the omnidirectional wheels with one or two degrees of freedom. The principle of operation of differential control lies in different speeds of traction wheels when the AGV changes the direction of movement. By turning the wheels at the same speed in the same direction, the AGV moves forward or backward. By rotating the wheels at the same speed in opposite directions, the AGV is rotated about its own axis. This bringing great benefits to the AGV, for example, a zero turning radius of the tractor. The disadvantage of this construction is the inability to overcome higher obstacles such as door thresholds and the like [7, 8, 9].

When designing the AGV concept, it is important that this concept satisfies the basic requirements, which represent a compromise between customer requirements and equipment manufacturer's capabilities.

As essential requirements, we define:

- maximum AGV height: 300mm;
- maximum load capacity: 400kg;
- maximum speed: 0,7 m/s;
- power supply: 24V (maintenance-free batteries)

##### 4.1. Traction unit design

When designing a traction unit, it is necessary to identify the conditions in which the equipment will be operate. The weight of the load, weight of the AGV without load, lifting speed, AGV speed with and without load, the surface and the ascent of the route and many other factors, whether directly or indirectly, affect the traction of the equipment. The weight of the AGV is determined from a 3D model, which contains all the necessary elements such as base frame, lift mechanism, wheels, accumulators and other purchased and manufactured parts which scale up the total AGV weight. The weight of the AGV electronics was estimated. The total estimated AGV weight was 195 kg. The weight of the AGV is also increased by using peripheral devices. The total weight of the AGV is therefore set at 220kg [3, 4].

To calculate the power needed to run-up the AGV and determine the appropriate DC electric motor, gearbox and drive wheels, it is necessary to determine the set of resistances acting on the AGV during operation in the hall (indoor - no wind). When calculating, we consider an evenly accelerated movement to a speed of 0,7 - 1 m / s.

#### 4.1.1. Driving resistances

To determinate AGV driving resistances is sufficient a basic calculation of driving resistances according to the following formula [3, 4].

$$F_{Total} = F_{AD} + F_{RR} + F_{ACC} + F_{RG} \quad (1)$$

The Aerodynamic drag ( $F_{AD}$ ) is determined by the aerodynamic shape of the vehicle body and is described by parameters such as drag coefficient ( $C_d$ ), projected frontal area of the vehicle ( $A_f$ ), velocity ( $v$ ) and air density ( $\rho_{Air}$ ) [3, 4].

$$F_{AD} = C_d \cdot A_f \cdot \frac{\rho_{Air}}{2} \cdot v^2 \quad (2)$$

At speed AGV of 1 m/s and the specified operating conditions is Aerodynamic drag neglected for the calculation.

The rolling resistance force ( $F_{RR}$ ) is mostly determined by the wheel tread, but also by parts of the traction unit. They are characterized by the rolling resistance coefficient ( $f_{RR}$ ), which is dependent on the vehicle's velocity. The mass of the AGV ( $m_{AGV}$ ) and mass of the load ( $m_L$ ) also has a linear influence perpendicular to the road and the climb angle ( $\alpha$ ) is determined by certification of AGV with max value  $2^\circ$  [3, 4].

$$F_{RR} = (m_{AGV} + m_L) \cdot g \cdot f_{RR} \cdot \cos(\alpha) \quad (3)$$

The Acceleration resistance ( $F_{ACC}$ ) depends on the weight of the AGV with load. The inertia of the rotating parts ( $I_{RP}$ ) is negligible at a speed of 1 m/s. [3, 4]

$$F_{ACC} = (m_{AGV} + m_L + I_{RP}) \cdot a \quad (4)$$

The climb resistance ( $F_{RG}$ ) depends on the road gradient and the AGV mass with load. [3, 4]

$$F_{RG} = (m_{AGV} + m_L) \cdot g \cdot \sin(\alpha) \quad (5)$$

#### Traction force ( $F_{Total}$ )

$$F_{Total} = 520 \text{ N}$$

#### Power ( $P_{Total}$ )

$$P_{Total} = 520 \text{ W}$$

#### Torque ( $T_{Total}$ )

$$T_{Total} = 57,2 \text{ Nm}$$

For the operation of differential chassis type equipment (two-wheel drive) is the total power distributed between the left and right traction units. Each of these parts includes an electric motor with a gearbox (or servo motor) and a traction wheel. Servomotors are the most suitable solution for AGV control, but they are very expensive compared to conventional DC electric motors. The proposed AGV prototype will be categorized as a low-cost type of AGV and it is preferable to select a system of an DC electric motor with a gearbox for traction unit. Transtecno s.r.o. offers, in its products, DC (electric) motors with worm gears. The advantage of such assemblies is their simple installation and operation with minimal maintenance [11, 12].

#### 4.1.2. Selected assembly

The following tables 1 and 2 describes the parameters of the selected DC electric motor type and the selected worm gearbox [11, 12].

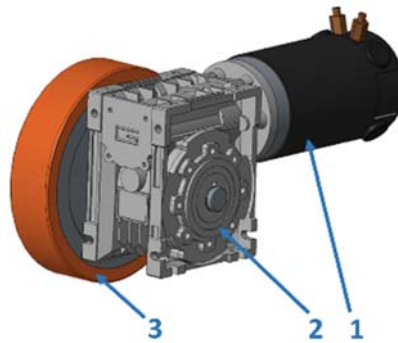
**Table 1.** Type of DC electric motor.

Type	NP [W]	NV [V]	NC [A]	NT [Nm]	NR [rpm]
EC 350.240	350	24	21	1,12	3000

**Table 2.** Type of worm gearbox.

Type	$i_G$	NR [rpm]	$\eta_G$	OT [Nm]	OP [W]
CM 063	50	900	0,61	136	0,6
		1400	0,66		
		2800	0,73		

**Acronyms:** NP – nominal power, NV – nominal voltage, NC – nominal current, NT – nominal torque, NR – nominal revolutions,  $i_G$  – gear ratio,  $\eta_G$  – gear efficiency, OT – output torque, OP – output power.



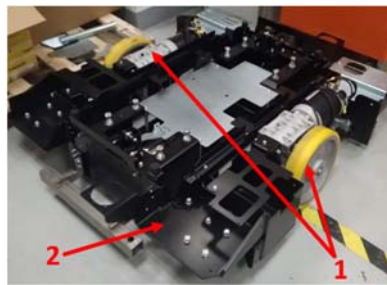
**Figure 3.** Assembly of 1 - DC electric motor EC 350.240, 2 - worm gearbox CM 063 and 3 - traction wheel.

The torque of the selected electric motor when the AGV acceleration is 1,12 Nm. It is the nominal torque value at the nominal motor speed indicated by the electric motor manufacturer. Check of the total output torque ( $T_{TO}$ ) of traction unit is performed as follows [3, 4]:

$$T_{TO} = 2 \cdot (T_{Total} \cdot i_G \cdot \eta_G) \quad (6)$$

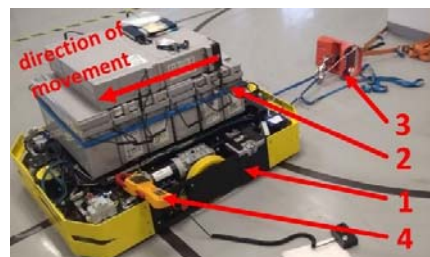
$$T_{TO} = 68,32 \text{ Nm} > T_{Total} = 57,2 \text{ Nm}$$

The resulting total torque of the traction unit is higher than the calculated torque required, and it can, therefore, be argued that the traction unit drive is dimensioned correctly and will be able to operate in the event of a small overload. This claim must be verified by the physical measurement of the AGV traction force under load. The equipment test conditions result from the required operating parameters, load: 400kg and max. speed: 0.7 m/s. The following figure 4 shows the position of the traction unit on the AGV frame.



**Figure 4.** Position of the traction unit  
1 – traction unit, 2 – AGV frame.

Torque verification was done by measuring the AGV traction force. During the test were measured two physical quantities. The current between DC motor and traction converter using Fluke 345 clamp multimeter and the second variable was ductility AGV measured by the industrial electronic crane scale with load capacity 5000kg and sensitivity 0,5kg. The following figure 5 shows the way how to measure the ductility of a device. An industrial scale (3) is placed between the AGV (1) and the concrete column. The AGVs, together with the industrial scale, are firmly fixed by means of clamping straps. The AGV is loaded with 8 batteries (2). Each of these batteries weights 54kg, resulting in a total load of 432kg.



**Figure 5.** AGV with load  
1 – AGV, 2 – load (batteries), 3 – industrial scale, 4 – clamp multimeter.

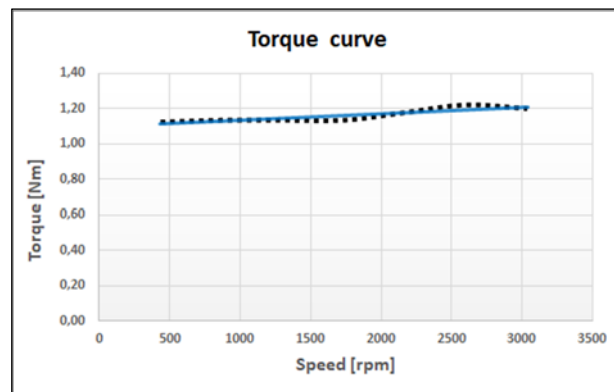
14 measurements were made after setting the measuring technique. Seven measurements at an electric motor temperature of 21 ° C and seven measurements at an electric motor temperature of 53 ° C.

At each measurement, the AGV acceleration was 0,05 m/s<sup>2</sup> and the constant speed was 0,1 – 0,7 m/s. After reaching a constant speed, the tensioning straps were tightened, and the electric motor stopped. The measured traction force at the stopped electric motor is equivalent to the maximum traction force needed to start the AGV. The following graphs show the torque curve of the electric motor, which is composed of the measured and calculated values given in the tables [14, 15].

**Table 3.** Results of first measurement.

CR [A]	PF [kg]	PF [N]	$i_G$	WR [m]	TR [Nm]	$v$ [m/s]	WS [rps]	MS [rpm]
32,00	104	1020,24			1,12	0,1	0,145	434
32,50	105	1030,05			1,13	0,2	0,289	869
32,6	105	1030,05			1,13	0,3	0,434	1303
32,6	105	1030,05	50	0,11	1,13	0,4	0,579	1737
32,6	109	1069,29			1,18	0,5	0,724	2171
32,6	113	1108,53			1,22	0,6	0,868	2606
32,6	111	1088,91			1,20	0,7	1,013	3040

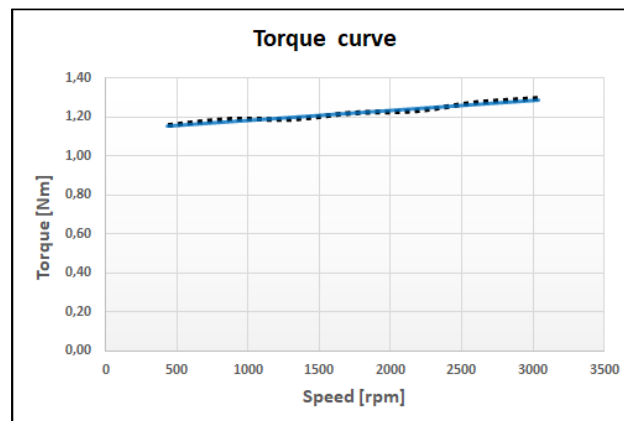




**Figure 6.** Torque curve of EC 350.240 – first measurement.

**Table 4.** Results of second measurement.

CR [A]	PF [kg]	PF [N]	$i_G$	WR [m]	TR [Nm]	v [m/s]	WS [rps]	MS [rpm]
32,7	107	1049,67	50	0,11	1,15	0,1	0,145	434
32,6	110	1079,1			1,19	0,2	0,289	869
32,6	110	1079,1			1,19	0,3	0,434	1303
32.6	113	1108,53			1,22	0,4	0,579	1737
32.6	114	1118,34			1,23	0,5	0,724	2171
32.6	118	1157,58			1,27	0,6	0,868	2606
33	120	1177,2			1,29	0,7	1,013	3040



**Figure 7.** Torque curve of EC 350.240 – second measurement.

**Acronyms:** CR – current, PF – pulling force,  $i_G$  – gear ratio, WR – wheel radius, TR – motor torque, v – velocity, WS – wheel speed, MS – motor speed.

The measured traction force values of the AGV confirm that the designed parts of the traction unit (DC electric motor and worm gearbox) are suitable for a low-cost version of medium-class AGV equipment. From the resulting values of both measurements, it can be argued that the traction force of the AGV is **1000N** (see table 3 and 4) and the electric motor torque of **1.12Nm will be sufficient** for the start acceleration AGV (see figure 6 and 7) because it is greater than the calculated maximum torque. The cost of this type of drive is much lower than that of servo motors, which guarantees a lower price for the AGV and more competitiveness device. The figure below shows the newly developed AGV



prototype for smart internal logistics, in which the proposed type of traction unit is used. This type of traction unit will be further tested in laboratory conditions and later directly in the warehouse operation for which this prototype is designed. The AGV type also includes the latest hardware components and software packages for autonomous location, navigation, and mapping of space.



**Figure 8.** Developed type of AGV 400LC-F during testing of the designed low-cost traction unit.

## 5. Conclusion and future work

This paper has described the optimization of traction unit for developed AGV. It is a low-cost version of the device for which it is also necessary to design a low-cost solution for each part of the AGV. In low-cost solutions, economic point is a major factor affecting those solutions. The main aim of the paper is to design a simple solution of parts of the traction unit and verify the proposed solution by physical measurement for the required parameters of the equipment. Testing of the equipment takes place in the laboratory of CEIT, a.s., which developed this equipment. The measurement results showed that the designed type of traction unit is a suitable equivalent of servomotors and it can be usable as AGV's drive.

In case of autonomous logistics tractors, it is necessary to use the parking brake when the AGV is stopped. This brake is usually located on the traction wheels or is part of the electric motors. The designed type of low-cost traction unit does not contain any braking system and therefore it is necessary to verify that the selected type of worm gear will meet the required braking parameters. On the developed prototype of AGV we will be testing brake force over the next few months of this year.

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