Use of brushless motors in autonomous vehicles

In light of technological developments such as IoT (Internet of Things) or Industry 4.0, manufacturers are looking for smart competitive advantages. One example is the growing trend towards driverless transport vehicles (AGV) and autonomous mobile robots (AMR), as well as the rise of automated storage and retrieval systems in both warehouses and production facilities. This paper shows why brushless DC motors are advantageous in the design of AGV and AMR.

Difference between AGV and AMR

AGVs and AMRs are mobile autonomous vehicles that are primarily used to transport products or materials in a warehouse or production facility. They help increase safety, efficiency and productivity while reducing product damage and costs. Larger, manually operated vehicles can thus be replaced by smaller AGVs or AMRs, for example, maximising warehouse density. These autonomous vehicles can be divided into two categories: Vehicles with assisted navigation and those with smart navigation.

Assisted navigation

An AGV is guided by a series of markers that can be detected by sensors. Some applications may require multiple types of markers for the AGV to navigate. The most popular navigation method is laser triangulation. In this method, the laser sensor on the AGV scans reflective objects placed at defined locations in the work area (Fig. 1). The vehicle triangulates the signals from the reflective objects and uses an algorithm to calculate its exact relative position and path. Other navigation methods include inertial navigation, grid navigation, magnetic tape navigation, embedded wire navigation, map navigation and optical navigation. These methods differ in the type of sensors or markers used.

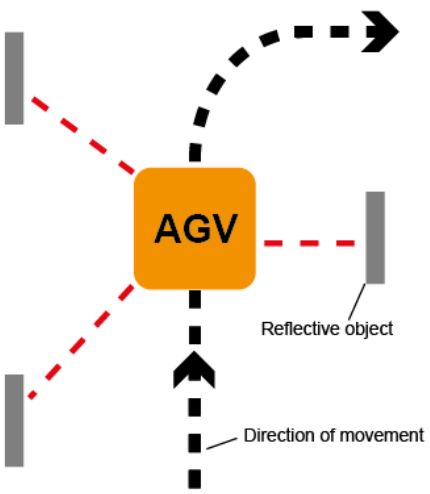

Fig. 1: Assisted navigation

Examples of the use of assisted navigation are driverless transport vehicles (AGV) or laser-guided vehicles.

Smart navigation

In contrast, an AMR is not steered and is independent of markers or reflective objects. This is helpful when reflective objects or magnetic markers cannot be placed. These newer, smarter AMRs include 2D or 3D mapping and sophisticated cameras, sensors and algorithms to make more of their own decisions. AMR often use Lidar (light detection and ranging) sensors. These use pulsed lasers and highly sensitive detectors to measure and range objects. This helps with simultaneous localisation and mapping technology to both create a map from an unknown environment and obtain a position within that map. With this advanced control, AMR can determine their own path to avoid obstacles (Fig. 2).

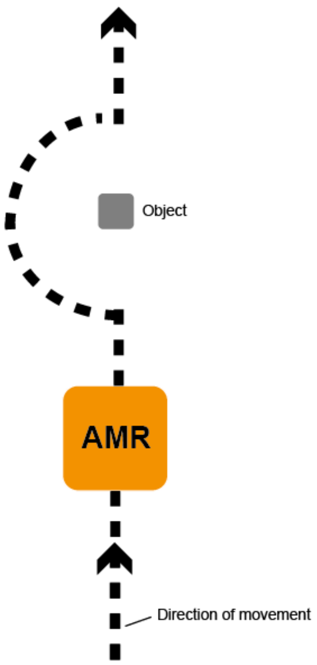

Fig. 2: Smart navigation

Examples of the use of smart navigation are autonomous mobile robots (AMR) or autonomous intelligent vehicles (AIV).

AGV/AMR construction

There are five central groups in AGV or AMR design: Battery, Controller, Sensors, Peripheral Mechanics and Powertrain.

1. The battery is the power source that provides the necessary energy for all electrical components of the vehicle. Battery types used include lead-acid batteries, nickel-cadmium batteries, lithium-ion batteries, inductive energy and fuel cells. Before the battery is exhausted, some AGV/AMR offer battery switching to continue operation. Some can be programmed to return to a charging station.

2. The controller takes over the function of a brain for the AGV/AMR. A PLC, PAC or IPC processes incoming sensor data and contains the necessary programming to operate autonomously. An HMI programming interface such as a touch screen or control panel is used for data input.

3. Different types of sensors act as the vehicle's eyes, providing data about the vehicle's environment. Obstacles can be detected in two ways: optical detection with laser sensors or mechanical bumper detection with pressure sensors. In addition, encoders, resolvers or Hall effect sensors are used to calculate the distance travelled and to check the speed of the vehicle.

4. Any movement outside the powertrain is defined as peripheral mechanics. In most vehicles, there is a lifting mechanism to raise the load, a door or an arm, which in turn are driven by motors or actuators.

5. The powertrain contains drive shafts, wheels, electric motors and gearboxes. These components move and steer the vehicle. The direction of the vehicle is usually controlled by synchronised or independent rotation of the wheels.

Powertrain design

The three-wheel drive is the most common drive design. One drive wheel and two non-driven wheels are aligned in a triangle. The single front drive wheel is used for both steering and moving the vehicle. A geared motor is required to turn the drive wheel and another motor is required for steering. The three wheels in this design provide sufficient manoeuvrability for most AGV/AMR applications.

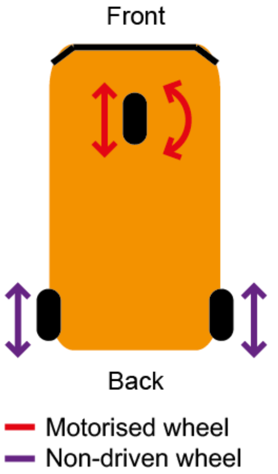

Fig. 3: Three-wheel drive

With differential drive, the vehicle steers via differential speed and direction of two drive wheels. This involves two geared motors for the drive wheels. The differential drive is extremely manoeuvrable as it can rotate around the centre of the vehicle, but the angular positioning is less precise.

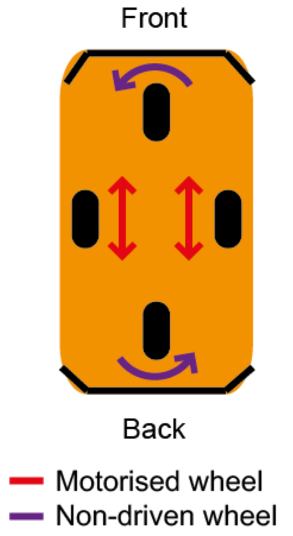

Fig. 4: Differential drive

The quad drive uses two steering motors and two drive motors. It is also extremely manoeuvrable, but more complex than other drive designs. The vehicle can move around the centre of its axle and also sideways.

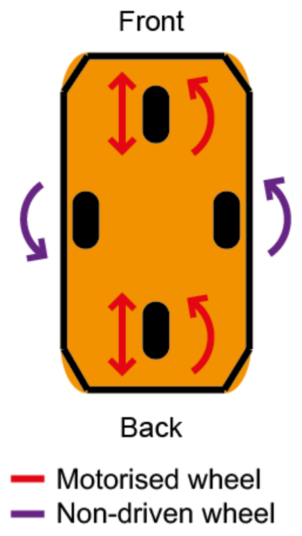

Fig. 5: Quad drive

Why brushless DC motors?

Battery friendly & better heat dissipation

Batteries produce a DC voltage, which makes them an ideal power source for DC motors. Typically, 24 or 48 VDC batteries are used, with which brushless DC motors can operate without problems.
High operating temperatures are a problem for heat-sensitive components in an AGV/AMR. Compared to brushed DC motors, brushless DC motors offer better heat

dissipation because the windings are usually located outside the rotor. Lower operating temperatures can help extend the life and duty cycle of the motors. Other options include stepper motors and servo motors. However, conventional stepper motors usually generate quite a lot of heat and the performance of servo motors comes at a higher cost.

Compact design

Minimising the space requirements of the individual components and the vehicle itself is important for applications with limited space. The compact size of brushless DC motors is therefore advantageous for AGV/AMR designers.

Oriental Motor offers brushless DC gearmotors in a particularly compact housing. The shorter length and wider motor housing allow for a larger rotor with higher inertia that can handle high load applications compared to conventional, long, cylinder-type brushless DC motors. The motor length is shorter compared to brushed motors (Fig. 6).

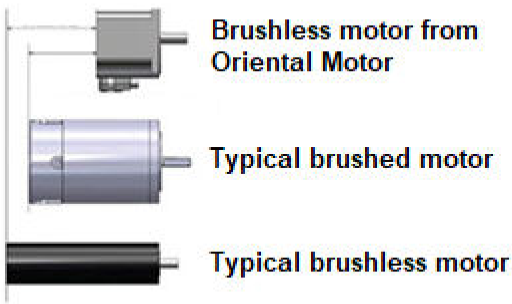

Fig. 6: DC motors in size comparison

No maintenance or electric arcing

To limit downtime for AGV/AMR, brushless DC motors offer an advantage over brushed DC motors because the former do not require brush maintenance. Brushes wear out over time with use and need to be replaced regularly. Brushless DC motors do not use brushes for electrical commutation. Therefore, their useful life is much longer, labour costs and downtime are reduced. Without the dust from the brushes as well as electric arcing problems, brushless DC motors can also be used safely in more environments than brushed DC motors. By using a driver to electrically commutate the windings instead of brushes, brushless DC motors also produce less electrical interference and audible noise than brushed DC motors.

Wide speed range, flat torque, closed-loop continuous duty characteristic

When moving objects from A to B, an AGV/AMR must be able to handle different speeds at constant torque. The wide speed range and flat torque characteristics of brushless motors allow designers maximum flexibility. Due to their high efficiency, brushless motors can be operated continuously without additional heat sinks, which increases productivity. The torque characteristic of a brushless motor is shown in Figure 7.

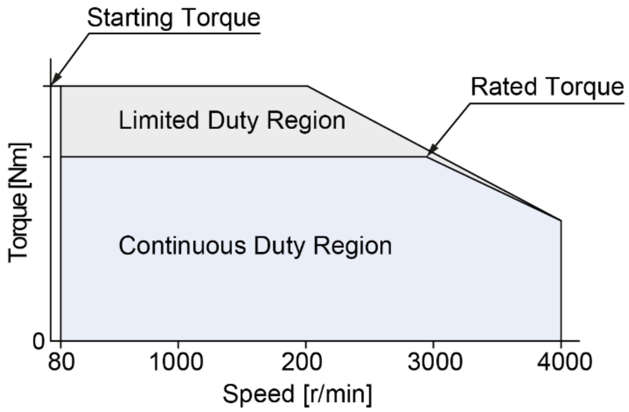

Fig. 7: Torque characteristic of a brushless motor

The closed loop control of a brushless DC motor is often achieved with feedback from Hall effect sensors. These sensors are located on the back of the motor and provide a signal to the driver for speed control. The basic feedback resolution on Oriental Motor brushless motors is 30 pulses per revolution (PPR). The driver can regulate speed deviations of +/- 0.5 % - thus achieving servo motor accuracy.

Motor feedback for zone control

Zone control requires a vehicle to detect objects in different proximity zones to determine warning or stopping behaviour. If an obstacle is in the vehicle's approach warning zone, it is recommended that the vehicle slow down and send an alert to notify personnel. If an obstacle is in the stopping zone closest to the vehicle, the vehicle should stop immediately. Zone detection can be further customised by the designer.

To achieve zone detection, there is the possibility of feedback. The drive motors need sufficient feedback resolution to quickly detect different zones within the map. Motor feedback, such as a Hall effect sensor, can provide digital pulses back to the driver for tracking. The standard feedback resolution of 30 pulses per revolution (PPR) at the motor shaft can be multiplied by the gear reduction ratio. A typical AGV/AMR application requires high torque and low speed, so high gear ratios are usually chosen for the gearmotor. In the next example we show you how the feedback resolution can be converted from the motor shaft to the drive gear.

Specifications:
30 PPR (on motor)
Gear reduction 50:1
Drive wheel with 25 cm diameter
Conversions:
1) Conversion from motor shaft pulse resolution to gearbox shaft pulse resolution:
30 PPR x 50:1 gear reduction ratio = 1,500 PPR.

2) Conversion of gear shaft resolution to degrees per pulse:
360 degrees / 1,500 PPR = 0.24 degrees per pulse

3) Conversion of degrees per pulse to linear distance per pulse:
(25 cm x π) / 1,500 PPR = 0.05 cm per pulse.

In most cases a resolution of 0.05 cm is sufficient for zone detection.

When stopping an AGV/AMR, other factors such as overrun come into play. The overrun for brushless motors at 2,500 rpm is about 2.6 revolutions at the motor shaft when working within the permissible load inertia. For a 25 cm diameter wheel with a 50:1 geared motor, this corresponds to 4.08 cm after the stop command is issued.

(2.6 revolutions / 50:1 reduction) x 25 cm x π = 4.08 cm.

The overrun varies depending on the speed, load inertia and motor size.

Brake functions

Requirements for AGV/AMR also exist in terms of braking functions such as emergency braking, parking braking and service braking. While hydraulic or pneumatic actuators are commonly used for emergency braking, motors with electromagnetic brakes can also be used to meet some of the requirements. A currentless activated electromagnetic brake uses friction to stop the motor shaft and hold it in position, this is ideal for a parking brake. In most cases, the motor and driver can also implement dynamic (electric) braking. Dynamic braking achieves an instantaneous stop by switching off the current to the motor and short-circuiting all phases together. This results in a locked rotor that prevents motor rotation. A combination of dynamic braking with deceleration and electromagnetic braking can take over the function of a service brake.

As the brake is worn by friction, it is recommended to use a dynamic brake to stop the motor and then activate the electromagnetic brake to park the vehicle. Buying standard motors with the electromagnetic brake installed ensures performance and shortens delivery time. The time required for installation and testing is eliminated as the specifications have already been tested and guaranteed by the manufacturer.

Gearbox options

Variety of shafts, gearboxes and mounting types

Choosing the right gearbox is the next important decision for a successful powertrain design. There are a variety of gearboxes with different configurations on the market, e.g. solid or hollow shaft as well as spur, worm, helical or hypoid gearboxes. While the gear shaft tends to influence the size of the powertrain, the gear type significantly determines the performance. Hollow shaft gearboxes, for example, can help minimise space requirements by eliminating the need for a coupling. Gear backlash can influence zone detection in bidirectional operation, and gear efficiency can influence payload capacity.

Apart from the type of shaft and gearbox, the mounting options of the gearbox must also be considered. The mounting orientation can be parallel or right-angled, and the mounting type can be foot or flange mounted. Gearboxes with foot mounting make the purchase or construction of a mounting bracket unnecessary, gearboxes with flange mounting save space.

Designers must select the gearbox that best fits the planned powertrain while delivering the required performance. In most cases, spur, helical or hypoid gearboxes are adequate, while inefficient worm gearboxes are not recommended for applications with heavy loads. As in the case of the built-in brake, buying a pre-assembled gearmotor saves time and manufacturer specifications are guaranteed.

Fig. 8: Spur gear

Fig. 9: Flat gear with hollow shaft

Space-saving flat gear with parallel hollow shaft

A popular gearbox in AGV/AMR designs is the hollow shaft gearbox. While many hollow shaft gearboxes are right angle, Oriental Motor offers a special combination of gearbox and motor. It is a flat gearbox with a parallel hollow shaft that is not only designed to save space, but also offers high torque and can be driven in reverse if required. This parallel shaft gearhead is in the portfolio for the brushless motors of the BLV-R and BLH series. With these parallel shaft gear units, mounting on both sides is possible, which can significantly reduce assembly time and labour costs - otherwise necessary components such as couplings, pulleys or belts are superfluous (Fig. 10).

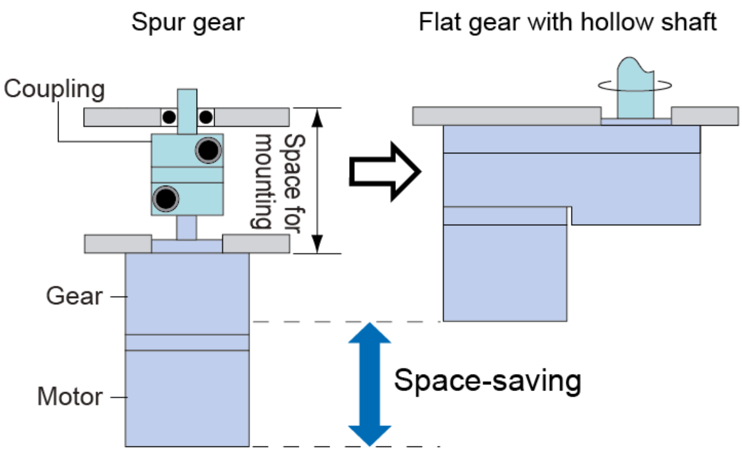

Fig. 10: Space saving through the use of a flat gear unit

High permissible torque

The flat gears offer a higher permissible torque than spur gears (Fig. 11). The flat gears have a higher stiffness and the longitudinal arrangement allows for larger gears. Both aspects result in a higher permissible torque on balance. The additional space in the flat gearhead also allows for larger bearings, which results in a higher radial load and increases the service life of the gearhead. Another advantage is the low noise level due to a fine mechanical treatment of the motor pinion shaft surface. Overall, AGV/AMR users benefit from low-noise operation with increased load capacity and extended service life.

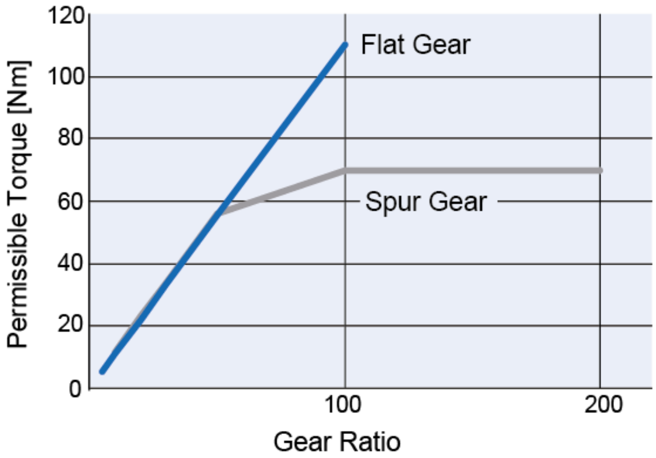

Fig. 11: High permissible torque of the flat gear

Drivers for brushless motors

User-friendly and flexible

Several people are involved in the use, control and programming of autonomous vehicles, and the control system should be correspondingly user-friendly. The brushless motor drivers meet this requirement and are easy to use. Some drivers allow I/O customisation for special applications.

The control of the speed and direction of the motors must be flexible and easy to implement in order to keep the development time short. Some autonomous vehicles use an analogue input signal (I/O) either in the form of a potentiometer or an externally fed analogue voltage of 0-10 VDC. Others use stored speed data that can be digitally programmed on the dedicated driver or via an industrial fieldbus network. Oriental Motor drivers include these functions.

Functions specially developed for AGV/AMR

Vector control is a built-in function used for constant speed ramp operation. This is an important function to ensure that the AGV/AMR is able to carry a load at constant speed when ramping up and down.

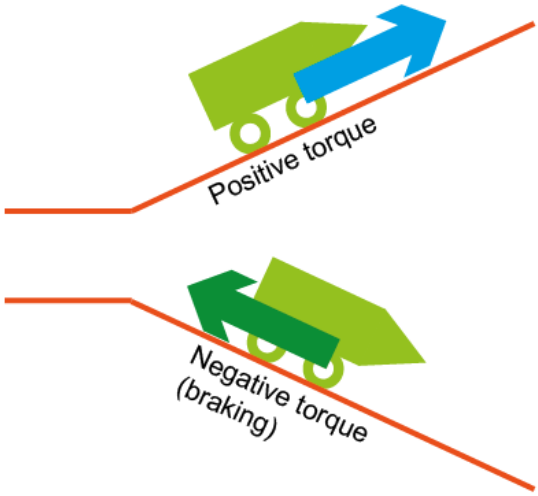

Fig. 12: Vector control for constant speed on up and down ramps

In ramp operation, the problem of back EMF (electromotive force) arises. This can occur, for example, when the motor is driven backwards by an external force such as gravity - the motor generates a voltage that is fed directly back to the driver. Similarly, back EMF can occur when the non-driven AGV/AMR is physically pushed or suddenly stops with a large inertial load. If the problem of back EMF is not properly addressed, it can lead to product damage. One method to reduce back EMF is to programme a longer deceleration time or incorporate driver features that delay the motor response.

A helpful feature is the "Speed Response Mode", a low response time here delays the motor response by applying a primary delay filter to the speed command information within the driver. This feature helps the motor to respond more slowly to reduce the back EMF generated.

Monitor function reduces downtime

Monitoring the condition of the motors and drivers in the vehicle enables preventive maintenance and can eliminate downtime. When alarms are triggered for the motors, the motors usually shut down until the problem is resolved. It is important to know about potential problems before these alarms are triggered, and this is where monitoring comes in. This requires closed-loop control with motor feedback. Both motor and driver status data must be passed to the master controller. This can be done with a PLC either via I/O or via an industrial fieldbus network such as Modbus RTU or CANopen.

Some motor and driver systems can provide feedback on temperature or mileage, preventing problems before they occur. In some cases, a warning signal can be given by the motor driver before an alarm is triggered. This allows the operator to intervene before the vehicle shuts down.

Summary

When designing the powertrain for AGV/AMR, brushless gearmotors offer several advantages.

The compact size, the wide speed range, the flat torque characteristic, numerous gear options such as the flat gear and the high-quality drivers provide an alternative solution compared to brushed motors. There are also cost advantages over servo motors. Among Oriental Motor's brushless motors, the BLV-R and BLH series in particular are ideally suited for use in autonomous vehicles.

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