

The concept of a mobile automated diagnostic and dynamometer station for heavy trucks

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Trucks are a key element that performs transport functions in many sectors of human activity. This makes ensuring their proper maintenance and performance critical. One of the solutions to this problem is the concept of a mobile automated testing and testing station. A mobile diagnostic and dynometric station based on a 6-foot container was built at the Military University of Technology in Warsaw. This bench is a self-contained unit that can be transported to various locations and carry out on-site testing and diagnostics of heavy trucks. The station is equipped with a fully open system and software that can accurately measure the performance and efficiency of the truck's engine and driveline and enforce specific automated diagnostic processes analogous to quality control tests during the production process. This information can then be used to make informed maintenance and repair decisions, helping to minimize downtime and increase overall vehicle life. The mobile diagnostic and dynamic station also provides a convenient and cost-effective alternative to traditional off-site testing methods, making it a valuable tool for transport companies and fleet managers.

Key words: *mobile dynamometer, automated tests, trucks, dyno*

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1. Introduction

A chassis dynamometer is a device most often used to measure the power and torque of a vehicle engine [19]. The measurement is carried out indirectly by recording the torque on the rollers of the chassis dynamometer. Referring the value of this parameter to the rotational speed of the rollers, and then, via the drive system, to the engine crankshaft drive speed, allows the vehicle power to be calculated (Fig. 1). Due to the specificity of their work, trucks generate very high values of torque on the wheels, which is necessary to move heavy loads while maintaining appropriate dynamics and in changing road conditions (e.g. changes in ground elevation or wind speed and direction). Forcing the engine to run under extreme conditions during no-load road tests is impossible or very difficult [16]. Therefore, a reasonable solution is to use a chassis dynamometer, which allows forcing appropriate working conditions of the drive system and maintaining them for a certain period of time.



Fig. 1. View of a truck on a chassis dynamometer [16]

Thus, the work of the vehicle on the dynamometer can perform basic tasks such as [19]:

- measurement of power and torque
- determination of the actual resistance to motion of the vehicle drive system.

However, as additional tasks, we can distinguish the ones that allow to simulate real load conditions that occur on the wheels of the vehicle while driving and the ability to simulate various load conditions and maintain certain conditions for a longer time (constant rotation, constant load) extending the diagnostic capabilities of the tested vehicle. This opens doors to non-standard applications [24].

Small mobile chassis dynamometers and mobile dynamometers loaded from the power take-off shaft, used in the heavy industry and agriculture, have gained popularity on the market mainly among tuning companies that offer modifications and tuning of vehicles [13, 26]. Thanks to the measurements on the dynamometer, it is possible to accurately determine the actual performance of the vehicle before and after making the changes, which allows the tuning to be adjusted to the individual needs of the customer and is extremely helpful in diagnostics. Dynamometers are also used in scientific research where they are used to test new materials, components and drive systems, and to study the impact of various factors on the efficiency and fuel consumption of vehicles, and their mobility allows to achieve vehicle operating conditions as close as possible to those in use. In the case of heavy trucks, apart from hub solutions, and one wheeled application, the market of mobile dynamometers is very narrow. This was the motivation to tackle this topic.

2. Characteristics and functionality

2.1. Diagnostic possibilities

Taking into account the diagnostic possibilities, possible applications for the discussed device/dynamometer can be selected, i.e.:

- checking the vehicle before shutting down or putting it into operation (after an accident, damage or repair) [9]

- evaluation of the vehicle's drivetrain wear level (e.g. torque and power analysis) [9]
- tuning (increasing power, modifications to the exhaust gas treatment system, mechanical modifications, eco tuning) [12]
- calibration of non-factory fuel supply systems (LPG, CNG, LNG, hydrogen) [15]
- measurements of emissions of exhaust gas components, fuel consumption (using an exhaust gas analyzer) [19, 20]
- the possibility of using automated procedures for assessing the technical condition of the vehicle using stations and dedicated OBD2 interfaces and tests implemented in them.

2.2. The mobility of the dynamometer

Convenience and Cost-effective are the factors where mobility of the station allows for on-site testing, reducing the need for trucks to be taken off the road and transported to a separate location for operation. The mobile station eliminates the costs associated with transporting the truck to an off-site location for testing, saving time and money. Servicing a large fleet of vehicles directly at the customer's machine park - in the case of modification of the fuel supply system or tuning it's a big advantage [2, 11]:

- Convenience and Cost-effective: The mobility of the station allows for on-site testing, reducing the need for trucks to be taken off the road and transported to a separate location for operation. The mobile station eliminates the costs associated with transporting the truck to an off-site location for testing, saving time and money. Servicing a large fleet of vehicles directly at the customer's machine park – in the case of modification of the fuel supply system or tuning it's a big advantage;
- Increased efficiency: By conducting diagnostics and testing on-site, the time required to diagnose and repair a truck is reduced, leading to increased efficiency and decreased downtime. This is of key importance when operating on the battlefield or, for example, during motorsport competitions;
- Improved accuracy: The advanced sensors and software used in the mobile station provide highly accurate measurements of the truck's performance, helping to identify potential problems before they become major issues;
- Increased accessibility: The ability to bring the station to various locations increases accessibility for fleet managers, allowing them to conduct testing and diagnostics even in remote areas;
- Increased safety: By conducting testing and diagnostics on-site, the risks associated with transporting the truck to an off-site location are reduced, improving the overall safety of the vehicles and the people operating them.

3. Construction of a mobile chassis dynamometer for trucks

3.1. Benchmarking of technological solutions

As part of the research, learning and creative use of the best market models at a given moment, only one company that implemented this idea was found. The company Tylor Dyno, from Milwaukee, USA, was the only one in the

world to deal with the subject. The company developed a mobile dynamometer for trucks, in a comprehensive style. Company used an 18-meter semi-trailer, a crane on board and a lot of spectacular automation as shown on Fig. 2 [17].



Fig. 2. Render of the mobile chassis dynamometer solution by Taylor Dyno [19]

The design of the mobile truck dynamometer form Tylor Dyno has a structure built on a semi-trailer, which makes it impossible to use this idea in non-road applications with an emphasis on military use. This solution also takes up a lot of space and requires a truck tractor to change the place of operation each time. Unfortunately, the solution found was far from meeting the needs of the designed device, which prevented deeper inspiration from market solutions.

3.2. Design, construction and testing

The design and construction process of a mobile automated diagnostic and dynamometer station for heavy trucks involved several stages [5, 17].

- Requirements gathering: The assumptions of various types of use (the original need to build a dynamometer was related to the project for mass modifications of trucks with dual-fuel CNG/diesel) and the dedicated possibility of military use in bad or unknown terrain meant that the chassis dynamometer designed at MUT had to be redefined comparing to Tylor Dyno solution. Due to this fact, the need to build a dynamometer station with the following design assumptions was put forward:
 - loading/unloading using a hydraulic lift which is an integral part of the transporting vehicle
 - provide the possibility of temporarily setting up a mobile diagnostic and dynamometer station at the customer's site for the duration of the assembly
 - the station is to be able to be folded into a standardized container for transport
- Conceptual design: Based on the requirements, a conceptual design of the station is created. This includes the overall layout of the station, the type of equipment to be used, and the overall functionality of the system as shown on the Fig. 3 below.
- Detailed design: In this stage, the conceptual design was refined into a detailed design. This included the design of the mechanical (as shown on Fig. 4 and 5), electrical, and software systems that make up the station. All model tests were also performed at this stage which is shown on Fig. 5.

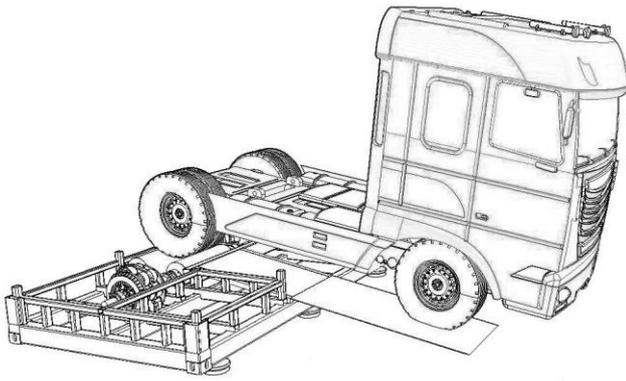


Fig. 3. Concept drawing of a mobile dynamometer for heavy trucks with the vehicle placed

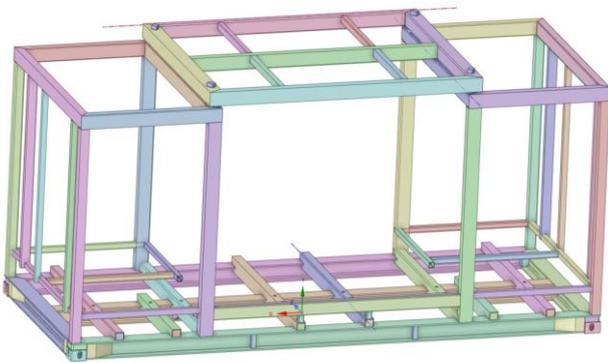


Fig. 4. Technical drawing of the mobile dynamometer support structure

The figure above shows the base of the dynamometer structure, for which a lattice structure with dimensions of a 6-foot sea container was used. In the upper part of the drawing it's noticeable a removable part of the roof of the container, enabling diagnosis on the rollers of the dynamometer of higher trucks with bodies.

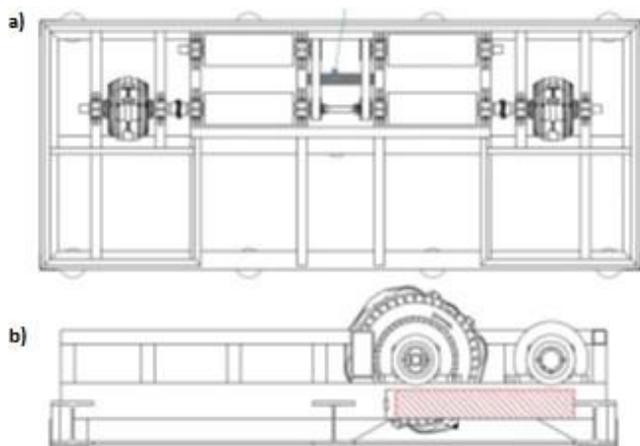


Fig. 5. Technical drawing of the low part of mobile dynamometer with the location of brakes and rollers: a) top view; b) side view

The Figure 5 above shows the low mounting of the roller assembly and eddy current brakes allowed to lower the center of gravity of the machine. The off-center offset of this assembly helped to reduce the angle of attack necessary

for the vehicle to climb onto the rollers. This allows vehicles with a small ground clearance to interact with the device and is of great importance, for example, in the context of road tractors or motorsport vehicles. The use of a removable roof and asymmetry in the location of the weight of the device required in-depth research on the stiffness of the load-bearing structure and its loads, which is shown in Fig. 6. This was crucial for maintaining the axially of the roller-brakes system and the possibility of multiple manipulation (moving) of the device without damage.

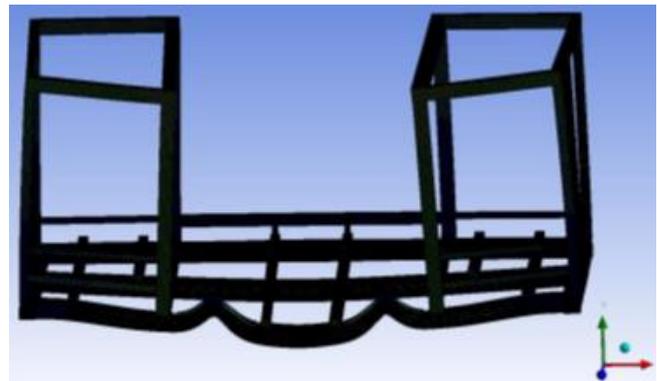


Fig. 6. Visualization of the mechanical load model of the mobile dynamometer structure

In Figure 6, there is a tendency to deformation on the axis perpendicular to the axis of the rollers and breaking deformations due to the removable roof. Engineers and designers had to strengthen the base structure and develop a roof structure that would transfer loads in the closed state (only in this state can the station be moved with a crane).

- Manufacturing and assembly: Once the design was finalized, the station has been manufactured and assembled. This included the fabrication of the mechanical components, the assembly of the electrical components, and the integration of the software. The project was implemented by members of a consortium consisting of the following companies: Dyno Revolt, Bart-Bud with the substantive and conceptual support of MUT. The author of this article was the designer and coordinator of this project.
- Testing and commissioning: The completed station has been thoroughly tested to ensure it meets all requirements. Problems that needed to be solved were also identified and a concept for further development of the station was developed (more on this in point 4 of this article). Validation included performance tests, reliability tests and security tests. The figures below show a general view of the station and the dynamometer station being tested before deployment.

During the tests starting operation of the station as shown on Fig. 7c and Fig. 7d, apart from typical things such as the correct operation of the electrical installation, software or correct operation of mechanical systems, they were also checked vibration levels, long-term operation under load and heat distribution were checked, the repeatability of measurements as well as the measurement systems themselves, i.e. strain gauges and rotational speed sensors.

More on this topic the author of this article wrote as part of the work [8].

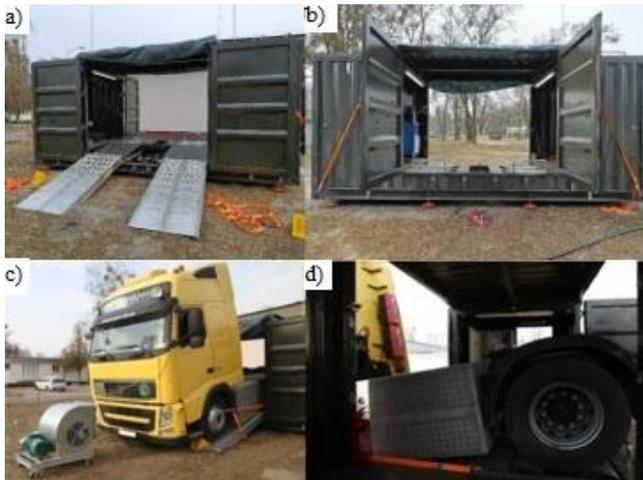


Fig. 7. General view of the mobile dynamometer station: a) front view with ramps; b) back view; c) view with the truck on the dyno; d) view of the wheels of the vehicle on the dyno

It should be emphasized that this article is a general aid to the recipient. More details on the construction can be obtained by contacting the author of this publication directly.

3.3. The final results

The station has been built on the construction of a 6-foot container and has a fastening system compliant with ISO 1161, i.e. the same as a standard sea container. This allows the dynamometer to be transported using standardized mountings [18]. The roof of the station is removable, which allows for testing vehicles with built-ups. On the Fig. 8 below, a view of the stations while being transported on a truck chassis.



Fig. 8. The diag- dyno station transported on a truck chassis

The dyno structure can be manipulated using the hydraulic crane provided with the vehicles (Fig. 9). The dynamometer can be transported through difficult terrain and set up and armed for operation in several minutes.

One of the goals of the researchers and designers was to leave the dynamometer architecture open in terms of hardware and software, as well as the possibility of designing proprietary operating modes. Therefore, the dynamometer controller has several connectors for digital and analog

signals, using USB Bluetooth or PWM controller support. In addition, the software has a fully configurable and compatible CAN protocol. What's more, measurements can be easily corrected according to DIN, EC, ISO, JIS and SAE standards thanks to the built-in weather station



Fig. 9. The diag- dyno station during unloading using a hydraulic truck crane

In the Table 1 below, some selected parameters of the dynamometer contoured by MUT are highlighted.

Table 1. Selected parameters of the mobile diagnostic and dynamometer station

Parameter	Value/Name/Type
Operating mode	Load, quasi-dynamic
Type of Brakes	2 × Frenelsa FF16 eddy current 3300 Nm
Max/Min track width	5700/1000 mm
Roller diameter, axle pressure system	320 mm, electric winch with tension reading
Dimensions, weight	6058 mm; 2545 mm; 2870 mm; 5574 kg
Transport system	Standardized 6ft container, ISO 1161 lashing system, handling with HDS
V-max on rollers	200 km/h
Modes of operation	Constant torque, constant speed, dynamic, load, ramp, combined
Temperature tolerance (operation) [storage]	-10 to +30 [-40 to +50] °C
Hardware driver	OEM DynoRevolt on Raspberry Pi 4, OBD2 compatible, HDMI connector, 4 × USB 3.0, 4 × HP analog input, 4 × analog input, 3 × low side PWM
Software	OS Debian Linux 5.4.14, OEM dyno software DynoRevolt "Dyno2 RPI 2.17.0" fully configurable, support for CAN, analog, digital PWM, bluetooth, USB and OBD signals, Measurements with corrections according to DIN 70020, EC 95-1, ISO 1585, JIS D1001, SAE J1349

The diagnostic and dynamometer station measures typical dynamometer values such as power, torque and all derivatives resulting from the possibility of programming your own test runs. It is worth noting that the software allows to read up to 166 real values of engine accessories using the vehicle's OBD connector (using a chip, e.g. ELM 327, STN1110). Leaving the system open allows more complex tests to be performed. Table 2 below summarizes selected values can be measured and those that may be

involved in the work of the dynamometer and the implementation of special tests on it.

Table 2. Selected measured, represented and involved in testing values used by discussed station

Parameter	Value/Name/Type
Engine speed [rpm]	Calculated engine speed
RPM acceleration motor speed [rpm/s]	Engine speed delta over time
Road speed [km/h]	Calculated linear "running" speed of the vehicle
Power loss [HP]	total power lost due to speed changes and load changes
Inertia power of the drive system [HP]	Inertia force of the drive system
Power on wheels [HP]	Calculated power at the wheels of the vehicle
Motor moment of inertia [Nm]	Calculated engine moment of inertia
Engine power [HP]	calculated engine power
Motor torque [Nm]	measured and calculated engine torque
Cor. engine power [HP]	corrected engine power
Ambient pressure [hPa], Ambient temperature [°C], Ambient humidity [%]	measured by the dynamometer's built-in weather station system
Cooperation with the vehicle's CAN line	Support for up to 166 actual values of engine accessories using the OBD connector of the vehicle (chip ELM 327, STN1110)

The device in this form has been put into operation, but solutions are being developed at the moment to extend its capabilities by carrying out automated diagnostic tests under load.

4. Automated tests CAN-dynamometer

To explain the possibilities offered by the open architecture of the dynamometer let's use an analogy to the possibilities integrated into the universal electronic external diagnostic system Bosch ESI [tronic] 2.0 KTS Truck [4]. Similar possibilities can also be found in other commercial solutions such as Texa or Delphi diagnostics solution [25]. At ESI [tronic] it's possible to perform many tests that can directly or indirectly tell about the condition of individual components of the engine and drive system. These tests enforce executive functions in the engine controller for the appropriate engine components in order to check their correct functionality [26]. For example, in the software KTS can "provoke" a test regarding:

- examination of the engine using a high-pressure test
- cylinder deactivation test
- compression test
- Adblue dosing test.

Many more are implemented

Let's take an example of a compression test for wallpaper. The current values read from the starter during its operation (without fuel doing which is forced by test algorithm) may indicate discrepancies as to the compression pressure in individual cylinders, this gives us a picture of what can happen to the engine without time-consuming disassembly or classic tests with a manometer.

In a similar way, we can carry out tests under load using the dynamometer's capabilities [10, 14]. The dynamometer

can maintain the operating parameters of the drive system in a given state while performing a test defined by us or sewn into its code. What's more, these tests can be blocked into entire test suites. Ultimately, it gives (similar to production control tests) comprehensive, quick knowledge about the actual condition of the vehicle and its drivetrain components. Diagnostics and non-destructive testing play a key role in keeping vehicles operational. They allow you to identify potential technical problems before they become serious problems, which can lead to vehicle failure and danger. Non-destructive testing allows you to detect damage and defects such as cracks, deformation or wear without having to dismantle or destroy vehicle components. Such tests include visual, measurement, ultrasonic, magnetic, penetrant and radiographic tests. In the context of using a dynamometer, testing of wheeled vehicles on them also fits into this definition.

The use of automated CAN-dynamometer tests using advanced technologies such as artificial intelligence, machine learning, data analysis and vision systems translates into more precise and effective diagnostics, which in turn leads to cost reduction or determines the success of a military mission or winning a race. Such investigations can detect potential technical problems and make repairs in time before they become serious safety hazards. In this way, damaged vehicles can also be deployed after repair with great efficiency.

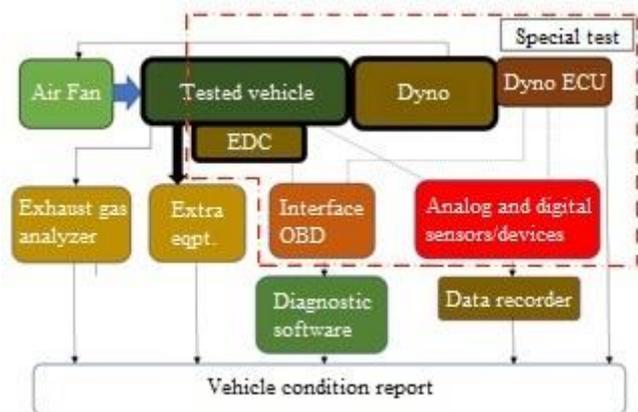


Fig. 11. A block set of elements necessary to perform forced special tests on a mobile chassis dynamometer

The picture above shows the test blocks algorithm. Real-world testing for heavy-duty vehicles may include checking the correct operation under load of components such as:

- the state of wear of individual sets of cylinder-piston rings
- the state of wear of the turbocharger
- the correctness of increasing the boost pressure
- proper operation of the wastegate valve
- correct operation of the engine brake and retarder
- testing the inertia of the drive system
- different tests including exhaust gases
- NVH test and durability can be selected depending on the application.

And much more in pre-programmed dedicated research systems. Tests can be fully automated and end with a ready

report on the status of individual elements. This allows for a quick and automated assessment of vehicle wear or damage, as well as a dynamic assessment of the vehicle's ability to return to service after a breakdown or collision.

5. Discussion

The concept of a mobile automated diagnostic and dynamometer station for heavy trucks built in MUT has great potential for revolutionizing the way in which heavy trucks are tested and calibrated.

One of the limitations of the device is the requirement for an open ECU architecture in order to achieve its full research capabilities. This means that the device and the special tests algorithm may not be suitable for use with all heavy trucks, as some with factory ECU closed setup may not be suitable. However, this limitation is not insurmountable, as open architecture is a typical configuration of vehicles modified in the context of e.g. motorsport [7].

In the case of military cars, the specification of the car delivered to the recipient is a matter of the needs of the army and related tenders [6], in which the exact parameters and functionalities of the vehicle are specified. If the military notices the potential of the dynamometer, adapting the vehicles and getting a new engine controller with an open architecture seems possible [7, 21].

However this device is capable of providing a wide range of special vehicle-dynamometer tests, and can be used for full-scale auto-calibration of external power supply systems, such as LPG or CNG. The use of the mobile automated diagnostic and dynamometer station has the potential to significantly reduce the costs related to modifying vehicles with auxiliary fuel supply. In today's applications,

the auto-calibration process is able to adjust the system settings only for low loads at engine idling speed [22]. Full-scale auto-calibration, which is necessary to modify the vehicle with auxiliary power, is a time-consuming process that requires people with appropriate knowledge. However, the use of the station and the algorithms embedded in it may result in a reduction of costs related to modification by several percent.

6. Conclusion

The mobile automated diagnostic and dynamometer station for heavy trucks built in MUT is a highly innovative device that has the potential to revolutionize the way in which heavy trucks are tested and calibrated. Although there are limitations to its use, the device can still be used for a wide range of special vehicle-dynamometer tests and full-scale auto-calibration of external power supply systems. The potential cost savings associated with its use make it an attractive option for those involved in modifying heavy trucks with auxiliary fuel supply [1, 25]. Overall, the device represents a significant step forward in the field of heavy truck testing and calibration. The diagnostic and braking station allows for handling external signals, including data from CAN, and has the ability to program special tests; The above makes it possible to carry out specific automated diagnostic processes analogous to quality control tests during the production process. Research on the topic is ongoing.

Acknowledgements

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Nomenclature

CAN	controller area network	JIS	Japanese Industrial Standards
CNG	compressed natural gas	LPG	liquified petroleum gas
DIN	Deutsches Institut für Normung e.V. (DIN; in English, the German Institute for Standardisation Registered Association)	MUT	Military University of Technology
EC	Directive 95/1/EC of the European Parliament and of the Council	NVH	noise, vibration, and harshness
EDC	electronic diesel control	OBD	on-board diagnostics
HDS	hydraulic truck mounted crane	PWM	pulse-width modulation
ISO	International Organization for Standardization	SAE	Society of Automotive Engineers
		UGB	university research grant
		USB	universal serial bus

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