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Design and Construction of Chassis Dynamometer for On-Site Testing of Tractors

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ABSTRACT

Measuring tractor performance parameters is crucial for validating manufacturer claims and selecting a suitable tractor. Field studies often face high costs and inaccuracies due to external factors and limited parameter measurement. A chassis dynamometer serves as an effective simulator for tractor movement on the ground. This research focused on designing and constructing an in-situ test system (chassis dynamometer) with practical features for measuring parameters at various speeds, loads, and conditions. An accurate data acquisition system records unlimited data based on relations between drawbar traction, speed, vertical load on driving wheels, and the distance to the center of gravity. To evaluate the system, the traction performance of an MF285 tractor was tested at different load and speed levels. The drawbar pull and dynamic axle load of the 2WD tractor were measured, with a maximum traction of about 11 kN. This study successfully designed and implemented an in-situ test system to assess the traction and balance capacities of conventional tractors by applying maximum load on the driving wheels.

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INTRODUCTION

Dynamometers are used to evaluate tractor performance parameters under controlled conditions (Al-Jalil et al., 2001). The chassis dynamometer is a dynamometer that is in contact with the driving wheels. Field testing of tractors has created some limitations in terms of weather. To avoid some problems of field testing, one of the methods is to use a chassis dynamometer. The device is located inside the ground and such a surface is relatively protected from weather changes and is used for tractor testing all year round. Because the tractor is placed on the machine and does not move, there is no rolling resistance for the front wheels, and this is an obvious defect of the system. When the tractor is tested on the chassis dynamometer, the temperature can be adjusted better. Also, in order to check and analyze the balanced behavior of the tractor and optimal traction efficiency, it is necessary to have correct and suitable parameters (Shafaei & Mousazadeh, 2024). Maximum performance efficiency and safe driving with a tractor is the result of using the maximum traction of the tractor and having dynamic loads on the wheels, so any improvement that can be made on the interaction of drawbar traction, rolling resistance, center of gravity and dynamic loads of the wheels will directly affect the performance of the tractor and reduction of fuel consumption (Barger et al., 1952). The performance of agricultural tractors is expressed in different ways. A criterion that describes performance better is the work that is taken from tractor. Since the power of a tractor is a function of speed and drawbar traction, it is clear that drawbar traction will only be a part of what a tractor does. Maximum drawbar power is usually the most useful performance criterion of agricultural tractors (Osetinsky & Shmulevich, 2004). It is very important to have data such as the traction resistance and drawbar power required by agricultural implements for optimal loading of the tractor as the only source of moving power in agriculture and as a result, choosing the right size of implements for tractors. Lack of accurate knowledge of traction values and failure to comply with the recommended values for parameters and lack of necessary coordination between weight, speed, power and slippage of driving wheels causes power losses and reduction of traction efficiency. On the other hand, the obtained traction and slippage is important in the maximum traction efficiency (Vahedi et al., 2022; Zoz, 1972). Weight transfer and traction in relation to each other are very decisive in obtaining some important parameters such as traction capacities, center of gravity and keeping balance in tractors. Since experimental methods have low accuracy and high cost, and analytical methods are not able to show all aspects of the dynamic process of tire-soil interaction, there is a need for a cheaper and more accurate way to predict traction for off-road car factories.

Also, the relation between traction force of drawbar and drawbar power is in the form of the following equation:

$$P_{db} = \frac{F \times V}{3.6} \tag{1}$$

where: P_{db} is the drawbar power in (kW), F: traction force in (kN), V: forward speed of the tractor in (km/h) (Dwyer, 1984). By having the above parameters, it is possible to achieve the drawbar power. But the experimental methods do not have enough accuracy, and in this case, it is not possible to simulate different situations in natural conditions. On the other hand, traction performance is affected by weight transfer. It is very difficult to measure the distances under field conditions and therefore the equations are not very useful in calculating the weight transfer. Zoz and Brixius formulated the following equation to calculate weight transfer:

$$\Delta R_r = (DWC).F_{db} \tag{2}$$

where: : : ΔR_r is the weight transfer to the rear wheels in kN, DWC: dynamic weight coefficient in decimal and F_{db}: traction force of the drawbar in kN (Zoz & Brixius, 1979).

Because the weight transfer depends on the dynamic weight coefficient, the use of the Zoz and Brixius chart to predict traction performance requires that the type of connection be determined. Weight transfer in tractors and cars plays one of the main roles in the control, guidance and safety of these devices. In addition, the better performance of the tractor in agricultural fields and providing optimal traction depends on the weight transfer and the amount of dynamic load on the drive wheels. In addition to the effect on the traction efficiency of the tractor, weight transfer also has a significant effect on the stability of the tractor in sloping fields. In agricultural activities, the tractor moves at an almost constant speed, so the weight transfer due to the traction of the implements is appeared more than other cases of weight transfer (Zoz et al., 2002). One of the factors influencing the production of traction force is the amount of weight on the drive wheels, so that if there is no appropriate amount of weight on the front wheels during farming operations in a four-wheel drive tractor, the traction that is Made by these wheels has decreased and the traction efficiency of the whole tractor will decrease (Burt et al., 1979). Therefore, it is necessary to estimate the amount of load on the front wheels by taking into account the traction force, the ground conditions, the slope of the ground, and the type of tools that are attached to the back of the tractor.

A dynamometer is a device that is used to determine the power of tractors and machines, and it usually works by independently measuring the force, speed, and distance that the point of application of force has moved. Drawbar dynamometers are designed to measure the forces applied to the drawbar of tractor by means of pull type implements. Field tests of tractors have created limitations in terms of weather (Servadio, 2010). To avoid some problems of field tests, one of the methods is to use a chassis dynamometer. The traction on drawbar is measured at the moment by this dynamometer, and the dynamic loads of each wheel are also measured by the designed scale and then analyzed. In most theoretical studies, parameters related to traction performance such as wheel dimensions and air pressure of tire, forward speed during work, weight distribution on axles, wheel slip percentage and conic index (CI) of field soil are measured, then using statistical average and the figures obtained and the formulas of empirical relations provided by other researchers, the amount of tractor power losses in traction operations are checked in relation to the real traction efficiency. In this study, a report on the stages of design, construction and performance evaluation of a chassis dynamometer is presented. This system provides the possibility of testing tractors without displacement and is capable of traction loading of tractors in more controlled conditions.

MATERIALS AND METHODS

The basis of the dynamometers is to create a load on the tractor up to its threshold of tolerance. In traction dynamometers, tractor performance is evaluated by creating a load in the form of traction force. This article presents a report on the construction and evaluation of a tractor traction power dynamometer. This system includes a digital scale, which has load cells with a nominal capacity of one ton in its four corners (Figure 1). This system is used to calculate traction and tractive power obtainable by the tractor in different conditions, check weight transfer, check dynamic load on tractor axles and other tractor performance parameters. The dimensions of this system are in accordance with the conventional dimensions of tractors, in such a way that necessarily, the tractor can be completely placed on the device and the system is able to measure the weight and load transferred on the driving wheels of the tractor. Using load cells and other equipment, the required parameters are measured, recorded and analyzed, and the tractor's drawbar power is calculated. This system consists of two parts: main chassis and secondary chassis. The main chassis has the function of a digital scale. The secondary chassis is designed to provide slippage and the ability to operate the rear wheels of the tractor on-site. In fact, the secondary chassis is a chassis dynamometer that simulates the conditions of the road or farm for the tractor, and the interaction of the soil-tire and the forces applied to the tractor are simulated in it. The main chassis in this system provides the possibility of measuring the total weight and the weight of each corner of the scale plate separately, and also makes it possible to simultaneously measure the dynamic load and traction created by the tractor.

Figure 2 shows the relation between the mobile chassis, the tractor and the fixed chassis. The basis of this system is based on the effort of the tractor to move and overcome the braking force that created on the contact surface of the wheels with the rollers. Figure 3 shows the free diagram of the mechanics of the distributed forces between the tractor and the mobile chassis. The force generated at the contact surface of the wheels with the rollers is equal to the force measured in the load cell connected to the tractor's drawbar and can be interpreted as the drawbar force. Also, the vertical load cells used in mobile chassis hangers show the amount of dynamic load on the wheels.

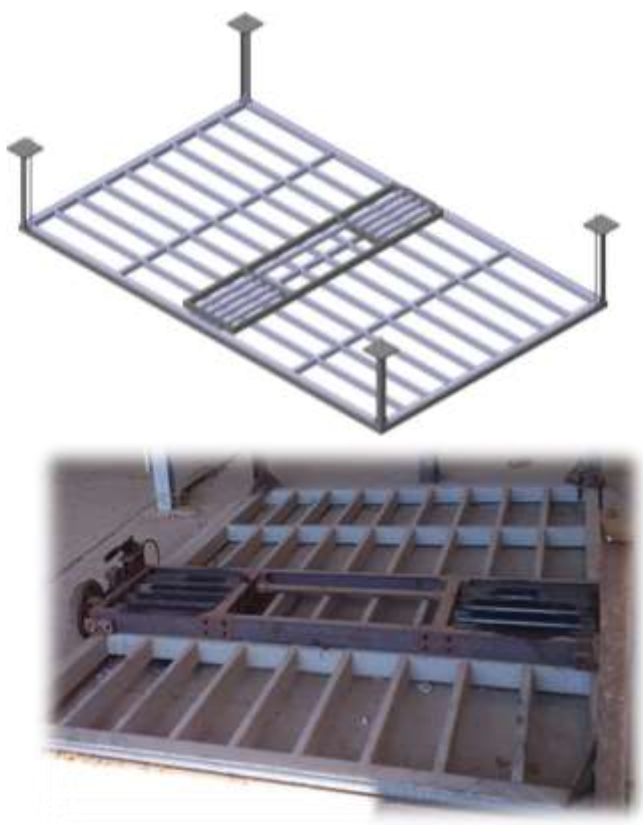

Figure 1. The system outline with secondary chassis

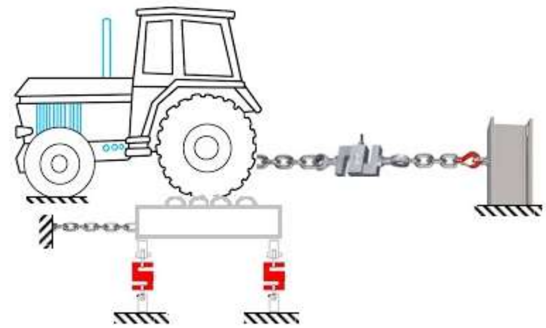

Figure 2. Schematic of the designed chassis dynamometer assembly

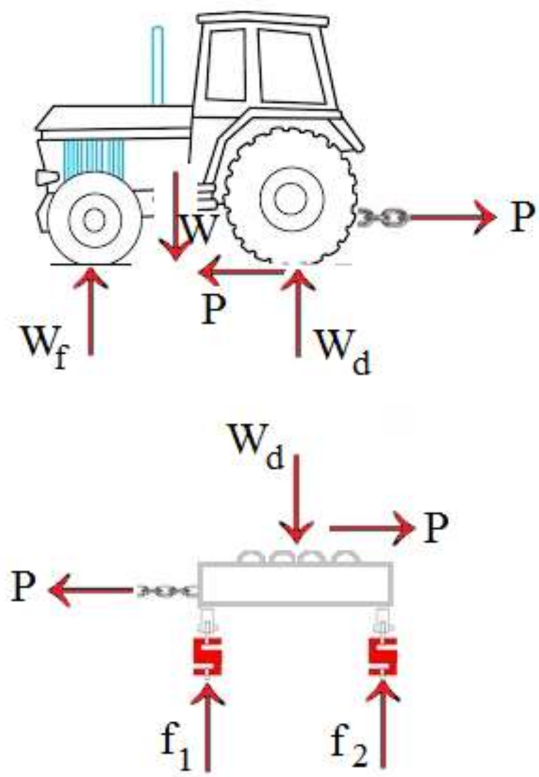

Figure 3. Free diagram of mobile chassis and tractor tested by dynamometer

On the secondary chassis, there are 4 rollers on each side that can rotate freely. The rear wheels of the tractor are placed on them, and when the tractor starts to move, the rollers start to rotate in the opposite direction, causing the wheels of the tractor to rotate on-site and simulating the movement on the road. To evaluate the maximum power of the tractor, these rollers need to be braked. Therefore, a strong braking system is needed to be able to resist the rotation of the rear wheels of the tractor. A drum-brake is used on the system. This brake is placed Next to the secondary chassis, and closed on the chain and sprocket system that connects the rollers together and has a lever that works like a handbrake and brakes rollers. Figure 4 shows the photo of the drum-brake of the chassis dynamometer.

Figure 4. Drum-brake system on chassis dynamometer

In the load cells system section, a 2 ton load cell and four 1 ton load cells are used to measure traction and vertical loads caused by the weight of tractor wheels respectively, that all of them are manufactured by Bongshin brand in South Korea. The 2-ton load cell is fastened between the tractor's drawbar and the girder that is installed behind the dynamometer chassis with high strength in the ground, and when the tractor starts trying to move, the 2-ton load cell measures the traction force applied by the tractor to the fixed girder. One-ton load cells are connected to the four corners of the main chassis, which are hung with chains from the four iron corners that are placed inside the ground, so that the main chassis is suspended and there are load cells in the four corners, and it acts like a digital scale. When the rear wheels of the tractor are placed on the main chassis, the weight or vertical force on the rear wheels can be measured. A rotation measuring system was used for the tractor wheel, and also the rollers engaged with the wheels, which are an indicator for the theoretical speed and the actual speed of the tractor respectively, and determine the amount of boxwatts, and thus the rotation of the rear wheel can be obtained and by applying the rotating radius of the wheels, the forward speed of the tractor can be calculated. To measure the sound intensity of the tractor engine in the environment, a TES sound meter was used, the image of which is shown in Figure 5.

Figure 5. The sound meter used in the tests

The data collection system of this dynamometer, which includes the data acquisition system and the interface cable and sockets between the load cells and the system, is used to collect data related to the load cells and rotation meters. This data logger system has 10 channels and is capable of recording data from load cells and rotation meters with a frequency of 80 Hz, which is shown in Figure 6. This system is connected to rotation meter, 2-ton load cells for measuring the traction force of the tractor and 1-ton load cells for measuring the dynamic load on the wheels through sockets and connecting wires.

Figure 6. The data logger system used in the tests

Testing and data collection

During the tests, the tractor was placed on the rollers as shown in Figure 7. The set of load cells including four 1-ton load cells after calibration were placed in the 4 corners of the chassis, which were connected to the data logger by a special cable and socket. Tests have been followed in two phases. In the first phase, at a constant braking level, all the combinations including three levels of engine speed 1200, 1680 and 1900 rpm and besides four gear levels from 1 to 4 heavy and over all 12 tests were performed. In the second phase, Tests have been planned and implemented to check the tolerance threshold of the tractor and by increasing the braking intensity of the drive wheels up to the maximum power of the tractor at 1680 rpm. In the first step, the load of the load cells was measured while there was no load on the chassis. Then, the rear wheels of the MF285 tractor were placed on the on-site test system so that the rear wheels were fully positioned in the center of the rollers. In this position, the static load on the wheels was measured by load cells. Then the tractor drawbar by a tow wire and a 2 ton load cell was connected to the girder which placed back of the chassis and it's end is in the ground to measure the amount of traction on each level along with the dynamic load on each wheel. The tests were conducted at three engine speed levels and four gear levels, and the results of rotation changes were recorded separately. Finally, the data obtained from the experimental tests have been drawn and analyzed in the Excel environment.

Figure 7. Placing the tractor on the dynamometer during dynamometer performance evaluation tests

RESULTS AND DISCUSSION

According to the conducted tests, the changes in dynamic load and weight transfer against the changes in traction indicate that the traction of the tractor has improved during the increase in the dynamic load on the drive wheels, and this increase has been noticed more in heavier gears and in the tests representing higher tractor speeds, the trend has been a milder increase.

On the other hand, it seems that the increase in traction of the evaluated tractor is not very impressive, contrary to the expectations of traction theory considerations. According to the mentioned considerations, a faster growth has been predicted for the traction, which seems to be related to the limitations of the tractor's power, so has not shown the ability to convert the dynamic load to the traction as well.

The tests related to the evaluation of the tractor performance showed that the weight transfer occurs due to the creation of traction, and based on the theory of traction, has improved it, and this event has also been observed during the conducted tests. Due to the frictional nature of the dynamometer mechanism, the weight transfer increases the dynamic load on the wheels, and therefore the amount of friction between the wheels and the engaged rollers increases.

Net traction coefficient is the ratio of net traction to the dynamic load on the driving wheels, which is an index to explain the amount of traction of a machine as a percentage of the load on the wheels. The results of the MF285 tractor test during this study indicated that less than 16% of the load on the wheels was converted into traction force by this tractor. On the other hand, the net traction coefficient has increased by increasing the speed conversion factor by the tractor, or in other words by making the gears lighter. Also, increasing the engine speed had a similar effect on the net traction coefficient and in both cases this effect was almost linear. Figure 8 shows the changes in net traction coefficient during loading at different levels of gear and tractor engine speed. Based on the results of this figure, the net traction ratio has increased in all three motor speed levels of the tractor with the increase of the gear level.

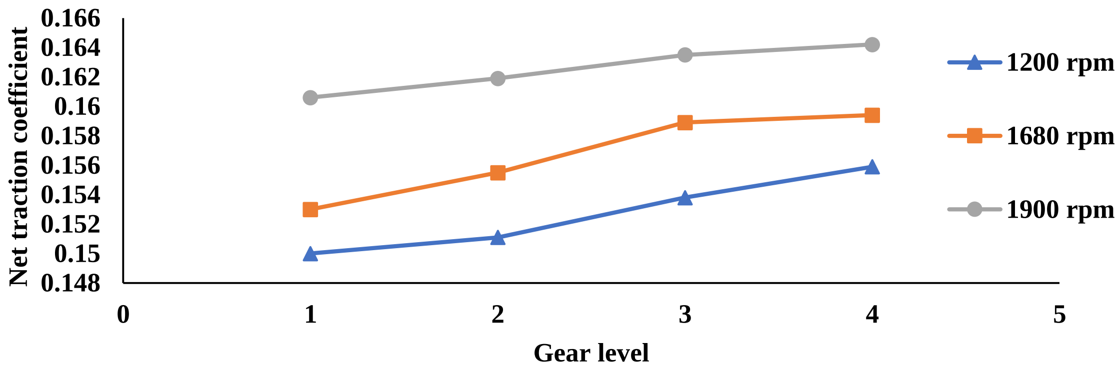

Figure 8. Changes in the net traction coefficient during loading at different levels of gear and engine speed

The dynamometer braking system used in this research was also braking the rollers engaged with the wheels, as an external load in the direction of stopping the tractor, and the amount of effort of the tractor to overcome these conditions is measured in the form of the forces created on the tractor body. For this purpose, tests with different gears were carried out by the dynamometer on the examined tractor, in such a way that at first the rollers engaged with the wheels rotate freely in engagement with the wheels and then gradually the rollers start to brake and this braking has continued until the threshold of the tractor's ability to continue rolling the wheels. Figure 9 shows the example of changes in traction as a result of increasing the intensity of engagement and wheel braking in one of the tests, which indicates an increase in traction simultaneously with the increase in the intensity of wheel braking.

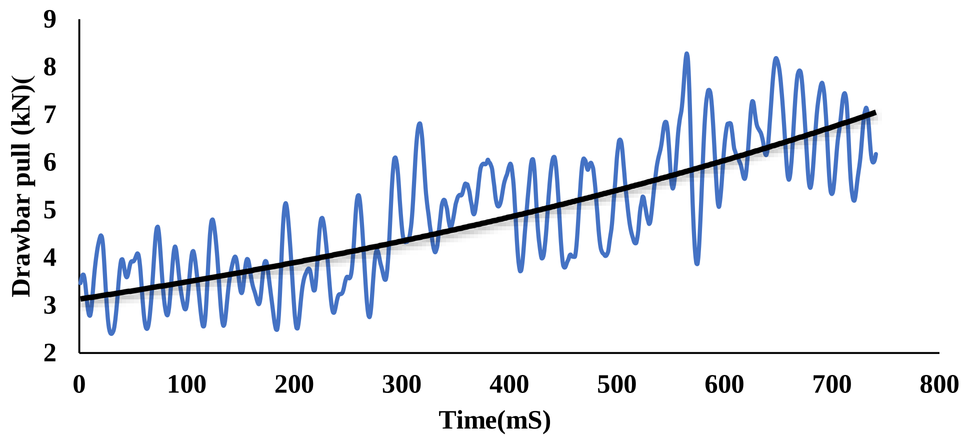

Figure 9. An example of traction changes due to the increase in the intensity of engagement and wheel braking

Evaluation of the maximum traction in braking conditions

The results of the tractor tests in the condition of gradual braking up to the threshold of the tractor's power indicated the production of a net traction is less than 11kN in the best conditions. This event has been observed almost at different gear levels, and in other words, by putting the tractor under pressure, an average traction of about 10 kN has been obtained. The same event is observed in the same way in the weight transfer due to the direct relationship between weight transfer and traction. As expected, the weight transfer has increased compared to the unbraked state, which is caused by the growth of the amount of net traction during more effective engagement of the wheels.

Figure 10 shows the weight transfer changes in the tractor at different gear levels at 1680 rpm. According to this chart, the amount of weight transfer decreases as the gears become lighter, so that there is about a 10% reduction in weight transfer with each successive gear change. The maximum weight transfer in the tested tractor was observed at about 2.5 kN, which is approximately equivalent to 15% of the static load on the driving wheels of the evaluated tractor.

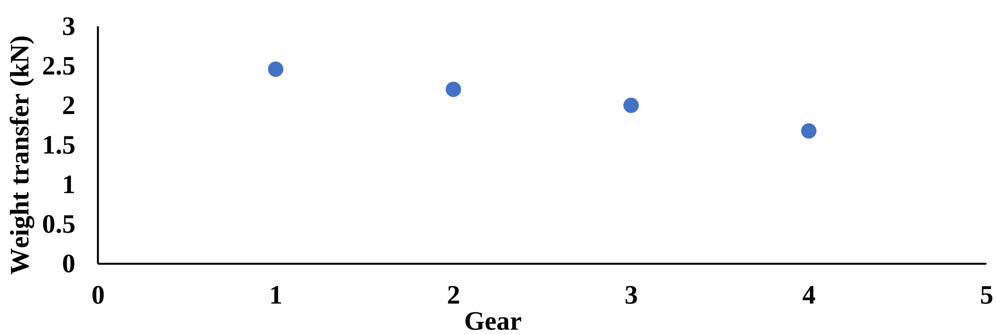

Figure 10. Weight transfer changes in the tractor at different gear levels at 1680 rpm

Evaluation of the traction power of the tractor

In order to evaluate the traction power of the tractor during the tests, the rotation of the driving wheels was measured using the rotation meter system, and on this basis, the forward speed of the tractor was calculated by applying the rolling radius of the wheels. The highest speed level of the tractor in heavy gears has been observed at about 1.25 m/s and considering the maximum amount of traction obtained in the tests which was less than 11 kilonewtons, the maximum drawbar power received from the tractor was less than 14 kilowatts which is about 20% of the nominal power of the tractor under test. Of course, this lack of power is not unexpected and a small part of the tractor's nominal power can be received in practical conditions.

Checking critical traction and stability

In order to avoid overturning around the rear wheels, it is necessary to neutralize the tendency to overturn caused by the drawbar traction by weight of the tractor. Considering that the maximum drawbar traction of the tested tractor was observed about 11 kilonewtons and by applying the mechanical characteristics of the tractor such as weight and mass geometry, the critical traction at the horizontal surfaces was calculated about 43 kilonewtons, so the possibility of the tractor overturning with the factor of safety around 4 seems unexpected, of course in the horizon surface and also without considering the impact loads.

Evaluation of sound intensity of tractor

In order to check the sound created by the tractor, using a sound meter, the average value of the sound in decibel was measured and recorded in each test. The test related to the sound evaluation of the tractor performance was done at four engine speed levels of 1200 rpm, 1680 rpm and 1900 rpm, all in four levels of gear 1 to 4.

Figure 11 shows the changes in tractor sound intensity during loading by dynamometer at different levels of gear and engine speed. As expected, with the increase in the load on the tractor through an increase in engine speed and lighter gears, the sound intensity has increased and these changes were observed somewhat linearly.

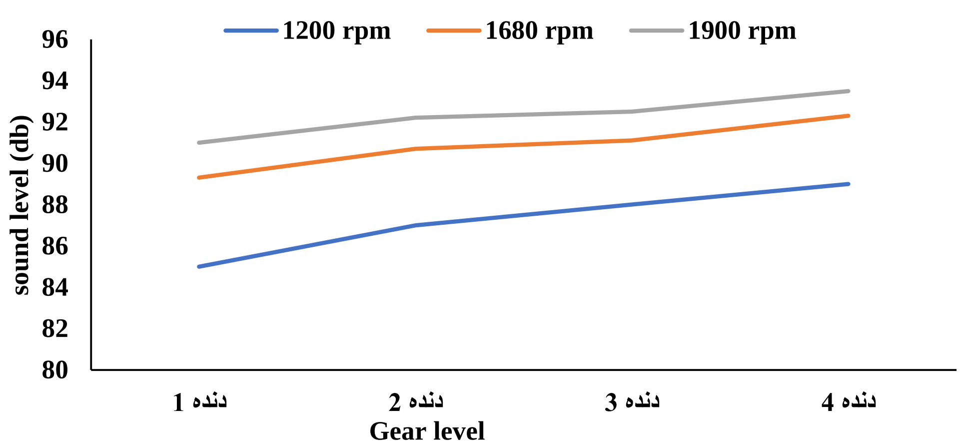

Figure 11. Changes in tractor sound level during loading by dynamometer at different levels of gear and engine speed

CONCLUSION

The most important goal of this research was to design and build an on-site test system for conventional tractors in the country, which was successfully implemented. The findings of this research, which includes a report on the design, construction and evaluation of a chassis dynamometer system, can be summarized as follows:

The on-site test dynamometer system was successfully used for an MF285 tractor and important parameters such as net traction and dynamic load were measured during traction loading of the tractor. This case was chosen to evaluate the performance of the designed system and showed the relative compatibility of the test results with the nominal characteristics of the tractor.

The tractor test by creating a gradual traction load has shown a direct relation between the net traction produced by the tractor and the dynamic load and the intensity of the wheel engagement through breaking the driving wheels.

During the examination of the net traction coefficient, the results of the MF285 tractor test in this study indicated that less than 16% of the load on the wheels was converted into traction force by this tractor.

The net traction coefficient has increased with lighter gears. Also, increasing the engine speed has a similar effect on the net traction coefficient, and in both cases, this effect was almost linear.

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