Abstract—This research presents methodology to design a program for controlling an electric motor chassis dynamometer using input signals from the rig. This research includes the method to calculate power and torque from inertia sweep type and electric motor brake type. A combination of mechanical and electrical loads of system in one dynamometer also can be controlled by the program. The load simulation system is constituted with an electric motor and two rollers. A roller of the test platform is connected directly to an electric motor. There is a load cell connected at the box of motor. And a controller is designed to control the electric motor to simulate driving resistance. The program can control the mechanical and electrical loads for vehicle demand at each speed when the car is in acceleration or in a constant-speed drive. And it also can simulate kinetic energy gained by the car when braking, deceleration and running downhill.

Keywords—Chassis Dynamometer, Dynamometer, Controller, Electric Motor, Inertia Sweep Dynamometer

I. INTRODUCTION

This paper briefly explains about basic concept of designing chassis dynamometer, theory of controller program, development of engine performance testing, and a few related studies and journals that have been done by current researchers. All this information is important before furthering to the analysis study and programming later. Otherwise this paper gave a design of program used to control a chassis dynamometer. The program can test the car with itself, no car.

II. FUNDAMENTAL OF DYNAMOMETER

Nowadays, dynamometer is widely used around the world. There were many people interested in it and did research. [1] A dynamometer, or "dyno" for short, is a device for generally measuring torque and power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm).

A. Fundamental of operation of absorbing dynamometers

An absorbing dynamometer acts as a load that is driven by the prime mover that is under test. The dynamometer must be able to operate at any speed and load to any level of torque that the test requires. Absorption dynamometers can be equipped with two types of control systems to provide different main test conditions: Constant Force and Constant Speed for setting the braking force and the wheel speed respectively.

Power in absorption dynamometer is calculated based on rotational speed \( \times \) torque \( \times \) constant, constant varies depending on output unit desired and input units used.

A motoring dynamometer acts as a motor that drives the equipment under test. It must be able to drive the equipment at any speed and develop any level of torque that the test requires. In common usage, AC or DC motors are used to drive the equipment or "load" device.

In most dynamometers power (\( P \)) is not measured directly; it must be calculated from torque (\( \tau \)) and angular velocity (\( \omega \)) values or force (\( F \)) and linear velocity (\( v \)):

\[
P = \tau \cdot \omega \tag{1}
\]

Or

\[
P = F \cdot v \tag{2}
\]

And

\[
\tau = F \cdot r = I \cdot \alpha \tag{3}
\]

Where,

\( P \) is the power in watts
\( \tau \) is the torque in newton metres
\( \omega \) is the angular velocity in radians per second
\( F \) is the force in newtons
\( v \) is the linear velocity in metres per second

B. Types of Dynamometer

There are many types of dynamometer as the information on Wikipedia [9]. This research focuses on "Electric Motor Type".

Measuring torque and power with dynamometer can be separated following test procedure for 3 types

1. Steady state (only on brake dynamometers), the engine is held at a specified car’s speed for a desired amount of time by the variable brake loading as provided by the power absorber unit.
2. Transient test (usually on AC or DC dynamometers), where the engine power and speed are varied throughout the test cycle.
3. Sweep test (be used on inertia or brake dynamometers), where the engine is tested under a load (inertia or brake loading), but allowed to "sweep" up in
speed continuous, from a specified lower starting speed to a specified end speed. From the equation of torque, in Nm, equal to moment of inertia multiply by angular acceleration, in rad/s². Therefore sweep test can measure torque by 2 methods.

- **Inertia sweep**: An inertia mass flywheel is fixed. Torque and power computed from acceleration of the inertia mass flywheel

- **Loaded Sweep Tests** (brake dyno type) consist of 2 types:
  a) **Simple fixed Load Sweep Test**: A fixed braking load which less than power of tested car is applied. This test, torque can be computed from torque from load-cell plus torque from acceleration plus torque added.
  b) **Controlled Acceleration Sweep Test**: This test is similar with simple fixed load sweep test, but fixing acceleration of roller instead braking load.

Controlled Acceleration Rate test is that the acceleration rate used is controlled from low power to high power engines and over extension and contraction of "test duration" is avoided, providing more repeatable tests and tuning results.

Types of dynamometer can be consisted in another way for engine dyno and chassis dyno.

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**III. PROVENANCE OF EACH PARAMETER**

This research focuses on programing to control a chassis dynamometer with electric motor, choose the chassis dynamometer of Thai-German-Graduate-School to be an example. Power and torque can be computed from equation 1 to 3. The parameters, roller’s radius, distance of load cell and moment of inertia, can be known from the structure of the chassis dynamometer. But $\omega$, $F$ and $\alpha$ can be known from measurement. Then Power and Torque will be found. Otherwise because the dyno can test a car in simple fixed load sweep test, therefore power require or power demand is necessary to be considered to find how much torque should be added while testing.

**A. Power Requirement/Demand**

In the research of DING-TSAIR SU [2], the provenance of power demand is following these below.

When the car is running, the electricity is transformed to kinetic energy to overcome the driving resistance. Driving resistance includes rolling friction resistance, drag force, moment of inertia, and uphill resistance and so on. Figure 2 is showing the driving resistance of car, wherein the rolling friction resistance-force $F_r$ is expressed in equation 4:

$$ F_r = \mu Mg \cos \theta $$  \hspace{1cm} (4)

In equation 4, $\mu$ is the coefficient of rolling friction resistance, $M$ is the total mass of the vehicle and rider, $g$ is the acceleration of gravity, and $\theta$ is the included angle of the road surface and the horizontal line. But as the friction between wheel and ground is transfer to the internal friction, in power-train system of a car. Therefore $F_r$ is not considered in car testing with chassis dynamometer.

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**Fig.2 The diagram of driving resistance**

When the car is running forward, the resistance produced from the vehicle external surface and the air is the drag force $F_D$, as expressed in equation 5:

$$ F_D = \rho C_d A \frac{V^2}{2} $$  \hspace{1cm} (5)

In equation 5, $\rho$ is the air density; $V$ is the vehicle speed, $C_d$ is the coefficient of drag, and $A$ is the orthogonal projection area of the rider to the vehicle moving direction. Because the car shape is irregular, the shape of the rider, riding posture and the clothes worn by the rider all affect the orthogonal projection area and the coefficient of drag.

The uphill resistance is expressed in equation 6:

$$ F_g = Mg \sin \theta $$  \hspace{1cm} (6)

As the driving force of the motor overcomes the rolling
friction resistance, air resistance and uphill resistance, the remaining driving force represents the moment of inertia, which is expressed in equation 7, wherein \( a \) is the driving acceleration.

\[
F_i = Ma
\]  

(7)

To summarize each driving resistance mentioned above, the uphill resistance \( F_g \) is related to the road surface inclination angle \( \theta \). The drag force \( F_D \) is in direct proportion to the square of vehicle speed, being very small when the speed is low, but is the most driving resistance when the speed is high. The rolling friction resistance \( F_r \) is like the maximum static friction force, the vehicle starts to move after the driving force overcomes the rolling friction resistance-force \( F_r \). After the vehicle starts to move, most driving force is spent on the acceleration until the constant acceleration \( a \) equals zero, then the acceleration resistance is also zero, at the moment the driving force equals the sum of the other three resistance forces. The driving resistance force of the overall vehicle is expressed by equation 8:

\[
F_R = F_D + F_i + F_g
\]  

(8)

According to the driving resistance force as design in equation 8, the drag-controlled system is as shown in Figure 4. The rotational speed is calculated from the signals which got from sensors, load cell and rotary encoders, except car speed. The basic theory of sensor is used in the researches of Sarapon Thitipatanapong[1] and C.Matthews [3].

**SENSORS-** A sensor device is used to measure by converting a physical quantity into a signal, which can be read by an observer or by an instrument. There are many types of sensors as in this research use 2 types of sensors, load cell and rotary encoder.

A rotary encoder is used for detecting the presence of rotating roller of chassis dynamometer without any physical contact. The rotary encoder always works by generating light and receiving the reflective light. Then it will send output signals to data acquisition as pulses. From these pulses, the controlling program can use them to calculate the speed of the roller.

For car speed in round per minute, it can be calculate from equation 9:

\[
RPM = \left( v \cdot N_g \cdot N_{diff} \right) / \left( 2 \cdot \pi \cdot r_{wheel} \right)
\]  

(9)

The car speed in RPM is calculate from car speed in meters per second \( v \) multiply by current transmission ratio \( gN \), where \( g \) could be 1-6, then multiply by differential gear ratio \( N_{diff} \) then divided by car wheel’s circumference. The current transmission ratio and the differential gear ratio can be got from car specimen from the company built that car. And car speed in meter per second is expressed by equation 10:

\[
r \cdot = \omega \cdot r
\]  

(10)

Where:

- \( r \) is roller’s radius in meter

**IV. PROGRAMING**

**A. LabView**

There are many methods to control a machine, for example; PLC, MCS, MatLab program, LabView program, etc. Many researchers chose LabView Program to use as the controller. [2][4][5][6]

LabView, Laboratory Virtual Instrument Engineering Work bench, is the software developed by National Instrument Company, NI. This company is one of the devices and software developers, devices and software which are used in measurement and automatic controlling.

This research also uses LabView as the data logging, calculating and controller program. Because of easily using, its extensive function and credibility, using LabView is an interesting way to control chassis dynamometer. But a program which is created on LabView have to be installed on a computer to use, therefore a device used to be the connector between devices of chassis dynamometer and computer is necessary.

**B. Data Acquisition Device**

From the researches of DING-TSAIR SU [2], Rungsan Chonpong [4], Patchara Sirigulyanon [5] and Chaiwat
Jetanacheawchankig [6], they used DAQ, Data Acquisition, devices to transform signal from machine to computer and from computer to machine.

This research also uses a DAQ device from NI Company. The DAQ device used is NI USB-6009 version, as shown in Fig.5, because of its function. For NI USB-6009, there are 8 analog input channels, 2 analog output channels and 12 digital input/output channels.

**C. Controlling Process**

The controlling process can be separated into 2 types, the closed loop and the open loop systems. For closed loop system or uncompensated system, C.Matthews and team [3] described in their research that for the standard torque measurement arrangement as used there, the structural dynamics of the load measurement arrangement including its torque arm, can be super imposed on the measured system response. This provides the torque measurement which an oscillatory nature which is difficult to be filtered without introducing unacceptable lag to the system. The removal of these unwanted and uncontrollable measurement disturbances would provide significant improvement to the fidelity of torque measurement. Therefore designing controller system as closed loop system or compensated system is better open loop system. C.Matthews[3], Rungsan Chonpong[4], Chaiwat Jetanacheawchankig [6], Ch. SALZMANN [7] and MOHAMED FARID BIN MOHAMED FARUQ [8] described about designing feedback controller.

In a chassis dynamometer control system, the torque controller is required to provide fast tracking of a transient torque demand signal which is generated by the road-load conditions. For satisfactory inertia simulation, fast response with limited over shoot and rapid settling are important. Controller performance must be achieved in the face of system uncertainty, due to nonlinearities and variations in system behavior due to environmental effects, as well as sensor noise and unwanted sensor dynamics. In the light of these factors, significant stability margins must be obtained. [3]

For feedback controlling, controller always tries to adjust output value equal to desired value or set point, SP. In the situation that there is noise disturbing to the process or changing desired value, output value will be different from desired value in time. Then the controller will try to control the output value equal to the desired value. This behavior is different from the characteristic of controller system. Some controller system may control the output value approaching to desired value fast. And some controller system may do it better that act as the response.

For these reason, close loop controlling an electric motor to generate drag torque equally calculated the power demand while driving is an important thing that has to be considered. Because of noise in the controlling process, the output signal of generated torque can cause error from the input signal of calculated signal.

**V. CONCLUSION**

Design of road load conditions for chassis dynamometer with controlling program from LabView is acceptable because of continuously controlling process of different road load conditions. Otherwise programing on LabView is not complicate and not long time spending. Many researchers did success with using LabView to create controller programs. Therefore this research chooses LabView to improve a program used to control a car chassis dynamometer. The program can measure and plot torque, power and speed in term of revolutions per minute. Otherwise there is a developed function of “Inertia Test with Road Load Conditions” which can test a car characteristic under the conditions of driving resistance from drag force, wheel rolling resistance and gradient force. The driving resistance can be generated from the electric DC motor of chassis dynamometer controlled by input signal of power demand. And after each test, the program always shows the torque-time graph and the power-time graph of the test.

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