Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 1, 2010, vol. LVI
article No. 1740

Radim ČECH [*], **Petr TOMČÍK** [**]

MEASUREMENT OF COMBUSTION ENGINE POWER CHARACTERISTICS, CORRECTION FACTORS

MĚŘENÍ VÝKONOVÝCH CHARAKTERISTIK SPALOVACÍCH MOTORŮ, KOREKCE VÝKONU

Abstract

This article primarily focuses on the measurement of combustion engine power characteristics and the issues of repeatability and comparability of measurements, including a particular adjustment of the SuperFlow SF-902 measurement system. The repeatability of measurements is influenced by a sum of variables which cannot be easily stabilized. Therefore, standardization institutions have developed sets of correction factors to unify the power characteristics measurements. Also, the correction factors are important for the comparability and repeatability of measurements. For this reason, the article also includes a brief description of the correction factor function and the issues concerning the extension of correction functions with the SuperFlow SF-902 motor brake. The SF-902 hydrodynamic motor brake is part of equipment owned by the Laboratory of Engine Testing and Dynamic Testing of Automotive Structural Groups, Institute of Progressive Technologies for Automotive Industry in Ostrava (hereinafter the "IPTAI").

Abstrakt

Primárně tento článek mapuje měření výkonových charakteristik spalovacích motorů a také problematiku opakovatelnosti a porovnatelnosti měření, doplněnou o konkrétní úpravu měřícího systému SuperFlow SF-902. Opakovatelnost měření je ovlivněna souhrnem mnoha proměnných veličin, které nemůžeme snadno stabilizovat. Proto byly vytvořeny normalizačními institucemi soubory korekčních součinitelů pro sjednocení měření výkonových charakteristik a pro potřeby porovnatelnosti a opakovatelnosti měření. Také proto je zde obsažen stručný popis funkce korekčního faktoru a problematika rozšíření korekčních funkcí na motorové brzdě SuperFlow SF-902. Hydrodynamická motorová brzda SF-902 je součástí vybavení Laboratoře testování motorů a dynamického testování automobilových konstrukčních uzlů, Ústavu progresivních technologií pro automobilový průmysl v Ostravě (dále jen ÚPTAP).

1 INTRODUCTION

As the combustion engine has been known since early 19th century and widespread since mid-19th century, requirements for power parameters measuring gradually arose. Measurements of the engines' performance facilitated experimental verification of the structural modifications. These adjustments were made to achieve efficiency gains and they also led to proven progress in reliability. Already in 1821, Gaspard de Prony invented the Prony Brake, which is considered to be the first dynamometer. Since then, in the modern times, many kinds of dynamometers have been invented. Even though today's dynamometer is obviously beyond the 19th century dynamometer technology, the basic principles of engine braking survived to this day [1] [2] [3].

[*] Ing., VŠB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Institute of Progressive Technologies for Automotive Industry, 17. listopadu, Ostrava
[**] doc. Ing., Ph.D., VŠB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Institute of Progressive Technologies for Automotive Industry, 17. listopadu, Ostrava

2 THE CUSTOMIZATION OF POWER CORRECTIONS ON THE SF-902 ENGINE BRAKE

The repeatability of measurements is influenced by a sum of variables which cannot be easily stabilized. Therefore, standardization institutions have developed sets of correction factors to unify the power characteristics measurements. Also, the correction factors are important for the comparability and repeatability of measurements.

SuperFlow accepted the procedure for power corrections of the SF - 902 brake from the SAE and DIN standardization institutions, which determine atmospheric conditions of measurements in order to make results comparable. Determined differences in temperature measurements are set at ±7% or below [4]. Apart from the intake air temperature, the standard defines also the atmospheric pressure and humidity [5]. Differing measured values arise with changing atmospheric conditions.

2.1 The Impact of Atmospheric Conditions on the Combustion Engine Function

Higher atmospheric pressures increase the air density and, therefore, augment the intake air charge to the engine. A higher intake charge improves the engine volumetric efficiency, and more power is delivered [6] [7] [8]. The ambient temperature is found to affect the flame speed, the combustion reaction rate, the uniformity of the fuel-air mixture, the volumetric efficiency and the heat transfer rate though the cylinder walls [8]. Higher intake air temperatures increase the occurrence of engine knock and decrease the volumetric efficiency [6]. Higher intake air temperatures can also contribute to stratified evaporation of the fuel components in the chamber. Each fuel component evaporates at a specific temperature, causing cycle-to-cycle combustion variations [7]. On the other hand, for lower temperatures, only a small part of the injected fuel is vaporized, causing no homogeneity. As a result, lower flame speeds, higher unburned mixture, higher hydrocarbons and carbon monoxide emissions, and loss of power are observed [6] [7] [8]. Pre-heated intake mixture at low rotational speed improves combustion. At high engine rotational speeds, higher intake mixture temperatures de crease the volumetric efficiency of the engine [14] found that engine brake torque, specific fuel consumption and volumetric efficiency vary inversely proportional to the square root of the suction air temperature. Air humidity influences the performance of an engine, though not comparable to the influence of pressure and temperature [9]. High air humidity decreases the thermal efficiency and, thus, reduces the engine mean effective pressure [10]. Also, increasing air humidity diminishes the flame speed, slowing down combustion [7]. High air humidity is beneficial to the engine at high cylinder temperatures, as it prevents the occurrence of knocking by heat absorption during the dissociation process of water molecules [7]. The presence of water in the intake air can also reduce oxides of nitrogen and carbon monoxide emissions [11].

Therefore, it is necessary to measure the engine under standard-defined atmospheric conditions. For comparable results, we need to create identical measurement conditions. We should maintain constant temperatures of air, fuel, oil and the coolant, as well as identical humidity and air pressure [4].

The combustion engine output is significantly affected by the barometric pressure, the ambient temperature and air humidity. Lower ambient barometric pressure is associated with a lower density of air, which reduces the amount of oxygen aspirated into the cylinder in each cycle. This results in a lower output. Lower air temperature results in increased density of air, thereby increasing the amount of oxygen in the cylinder and the engine output. Lower humidity (lower water vapor content) creates more space for oxygen and more oxygen in the cylinder then again leads to higher performance [4] [12].

2.2 Standards

Standardization institutions have defined methods for estimating the engine power outside the reference conditions. The best known are the following:

- International Standards Organization (ISO), standard ISO 1585-1992
- Society of Automotive Engineers (SAE), standard SAE J 1349-1990
- European Community (ECE), standard TRANS/SC1/WP29/R34/Rev.1 ECE
- Japanese Institute for Standardization (JIS), standard JIS D 1001-1993
- Deutsche Industrie Norm (DIN), standard DIN 70020-1986

Power correction standards for petrol and diesel engines are designed for automotive, stationary, marine and other engines. Power correction standards are designed to estimate the performance in non-standard conditions and cannot be used for the calculation of exact output values. The greater is the differences in atmospheric conditions, the greater is error in estimate. Standards cover the limits of these corrections' applicability. The limit is around ±7%, and therefore, the correction factor must be in range from 0.93 to 1.07. Measurements are not formally applicable outside of this range. Corrections are applicable only for measurements with a wide-open throttle (WOT). The SuperFlow system includes corrections of performance in compliance with the SAE and DIN standards.

Therefore, the need arose to adapt the WinDyn software to enable power corrections according to the ISO and ČSN standards. The WinDyn software is used by SuperFlow for processing and storing of measured data. The program is partially programmable and enables adjustment of individual calculated output data channels. Due to the variability of the program, new numerical data channels can be created for the correction of the torque and power pursuant to the ISO 1585-1992 international standard and the Czech ČSN 30 2008-1980 standard.

2.3 Correction Factors

At first, we need to know that standards differ, and therefore, different methods are listed below for power corrections of atmospheric ignition engines according to individual standards.

DIN 70020-1986 Automotive engineering, tyres and wheels, concepts and measuring conditions indicate reference atmospheric condition:

Reference atmospheric pressure.. $p_0 = 1{,}01325 bar$

Reference ambient air temperature. .... $T_0 = 293K$

Correction Factor [13]:

$$CF_{DIN} = \frac{P}{P_0} = \left(\frac{p_0}{p}\right) \cdot \left(\frac{T}{T_0}\right)^{0{,}5}$$

where:

P – Output power $[\mathrm{W}]$,

P_0 – Reference output power $[\mathrm{W}]$,

p – Atmospheric pressure $[\mathrm{bar}]$,

p_0 – Reference atmospheric pressure $[\mathrm{bar}]$,

T – Ambient air temperature $[\mathrm{K}]$,

T_0 – Reference ambient air temperature $[\mathrm{K}]$,

SAE J 1349-1995 Engine Power Test Code, Spark Ignition and Compression ignitron, Net Power Rating indicate reference atmospheric condition:

Reference atmospheric pressure.. $p_0 = 0{,}99 bar$

Reference ambient air temperature .... $T_0 = 302{,}4K$

Reference water vapor partial pressure .... $p_{v0} = 0{,}013 bar$

Correction Factor [14]:

$$CF_{SAE} = \frac{P}{P_0} = \left[\frac{(p_0 - p_{v0})}{(p - p_v)}\right] \cdot \left(\frac{T}{T_0}\right)^{0{,}5}$$

where:
P – Output power $[\mathrm{W}]$,
P_0 – Reference output power $[\mathrm{W}]$,
p – Atmospheric pressure $[\mathrm{bar}]$,
p_0 – Reference atmospheric pressure $[\mathrm{bar}]$,
p_v – Water vapor partial pressure $[\mathrm{bar}]$,
p_{v0} – Reference water vapor partial pressure $[\mathrm{bar}]$,
T – Ambient air temperature $[\mathrm{K}]$,
T_0 – Reference ambient air temperature $[\mathrm{K}]$,

ISO 1585-1992 Road vehicles, Engine test code, Net power indicate reference atmospheric condition:
Reference atmospheric pressure.. $p_0 = 1{,}0 bar$
Reference ambient air temperature .... $T_0 = 298K$
Reference water vapor partial pressure .... $p_{v0} = 0{,}010 bar$
Correction Factor [5]:

$$CF_{ISO} = \frac{P}{P_0} = \left[\frac{(p_0 - p_{v0})}{(p - p_v)}\right]^{1.2} \cdot \left(\frac{T}{T_0}\right)^{0,6}$$

where:
P – Output power $[\mathrm{W}]$,
P_0 – Reference output power $[\mathrm{W}]$,
p – Atmospheric pressure $[\mathrm{bar}]$,
p_0 – Reference atmospheric pressure $[\mathrm{bar}]$,
p_v – Water vapor partial pressure $[\mathrm{bar}]$,
p_{v0} – Reference water vapor partial pressure $[\mathrm{bar}]$,
T – Ambient air temperature $[\mathrm{K}]$,
T_0 – Reference ambient air temperature $[\mathrm{K}]$,

ČSN 30 2008-1980 Road vehicles´ engines, Test code indicate reference atmospheric condition:
Reference atmospheric pressure.. $p_0 = 1{,}0 bar$
Reference ambient air temperature .... $T_0 = 298K$
Correction Factor [15]:

$$CF_{ČSN} = \frac{P}{P_0} = \left(\frac{p_0}{p}\right) \cdot \left(\frac{T}{T_0}\right)^{0,5}$$

where:
P – Output power $[\mathrm{W}]$,
P_0 – Reference output power $[\mathrm{W}]$,
p – Atmospheric pressure $[\mathrm{bar}]$,
p_0 – Reference atmospheric pressure $[\mathrm{bar}]$,
T – Ambient air temperature $[\mathrm{K}]$,
T_0 – Reference ambient air temperature $[\mathrm{K}]$,

2.4 Substitution of Correction Variables with the WinDyn Program Data Channels

In the WinDyn program, we work with measured values which are generated by different types of sensors. The values are generated in the form of data channels to enable the work with them. Each channel has a specific name. Therefore, we can use a calculation formula when creating a new data channel and create a new measured quantity from individual channels. In our case the correction factor complies with the ISO and ČSN standards. It should be noted that other data channels related to the calculation have to be adjusted prior to the calculation of the corrected power. This approach is illustrated using an example of the final sequence and shape of formulas embedded in the WinDyn program (refer to Fig. 1 and 2):

With standard ISO 1585:

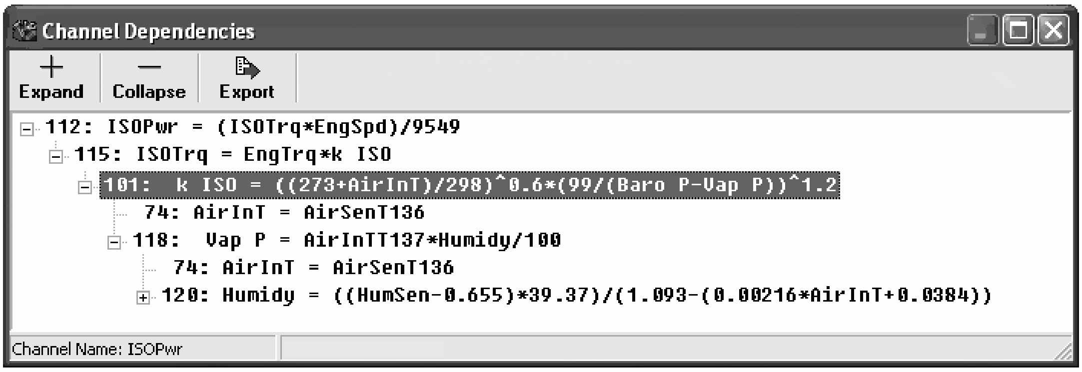

Fig.1 Preview of ISO correction in the WinDyn-Configuration Utility-Channel Dependencies

With standard ČSN 30 2008:

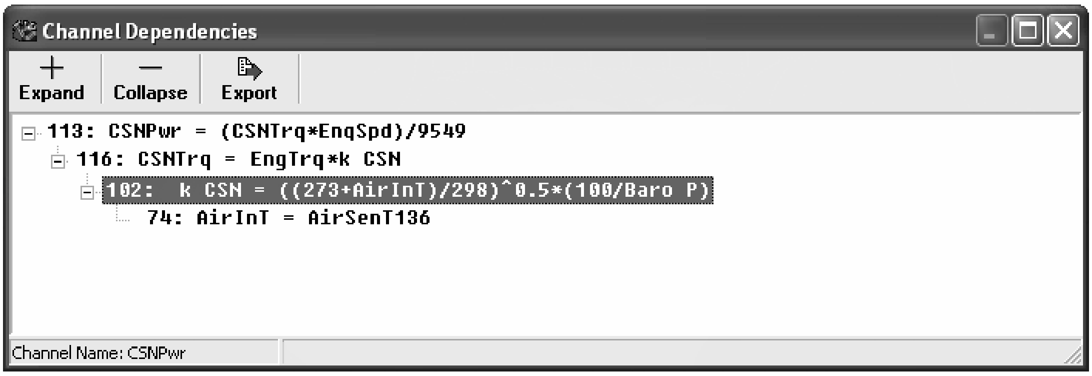

Fig.2 Preview of CSN correction in the WinDyn-Configuration Utility-Channel Dependencies

Description quantities let us say, that data channel is tabularly summarized see.Tab. 1

Tab. 1 Table data channels

Chanel name	**Physical property**	**Property description**
k ISO [-]	CF_{ISO} *[-]*	Correction factor for standard ISO 1585
k CSN [-]	$CF_{ČSN}$ *[-]*	Correction factor for standard ČSN 30 2008
AirInT [°C]	*T[K]*	Ambient air temperature
AirSen [V]		Voltage on air temperature sensor
Baro P [kPa]	*p[bar]*	Atmospheric pressure
Humidy [%]		Relative air humidity
HumSen [V]		Voltage on air humidity sensor
Vap P	P_v*[bar]*	Water vapor partial pressure
ISOPwr[kW]		Corrected power for standard ISO 1585
ISOTrq[Nm]		Corrected torque for standard ISO 1585
CSNPwr[kW]		Corrected power for standard ČSN 30 2008
CSNTrq[Nm]		Corrected torque for standard ČSN 30 2008
EngSpd[RPM]		Engine speed
EngTrq[Nm]		Engine torque
Tn [-]		Interpolate expression through table n.

2.5 Implementation into the WinDyn Software

Formulas implementation was carried out by creating a new file using the WinDyn Data Definition Ver.5-4 subprogram. This file contains definitions and functions of all available data channels.

2.6 Comparison of the Corrected Power Characteristics

The following figures show measured and corrected power characteristics. The Škoda 781.136 engine was measured under these atmospheric conditions: atmospheric pressure of 96.5kPa, air temperature of 10.7°C and air humidity of 36,6%. Other parameters of the measurement conditions:

Fuel temperature 18,5°C

Engine coolant temperature 89°C

Engine oil temperature 98°C

Figures 3 and 4 show the course of the measured dependence of the torque on the engine speed (Torque (Nm)) and a corrected estimate pursuant to the standards. Other shown dependences illustrate the corrected characteristics identified according to the names of standards (DIN, SAE, ISO, ČSN).

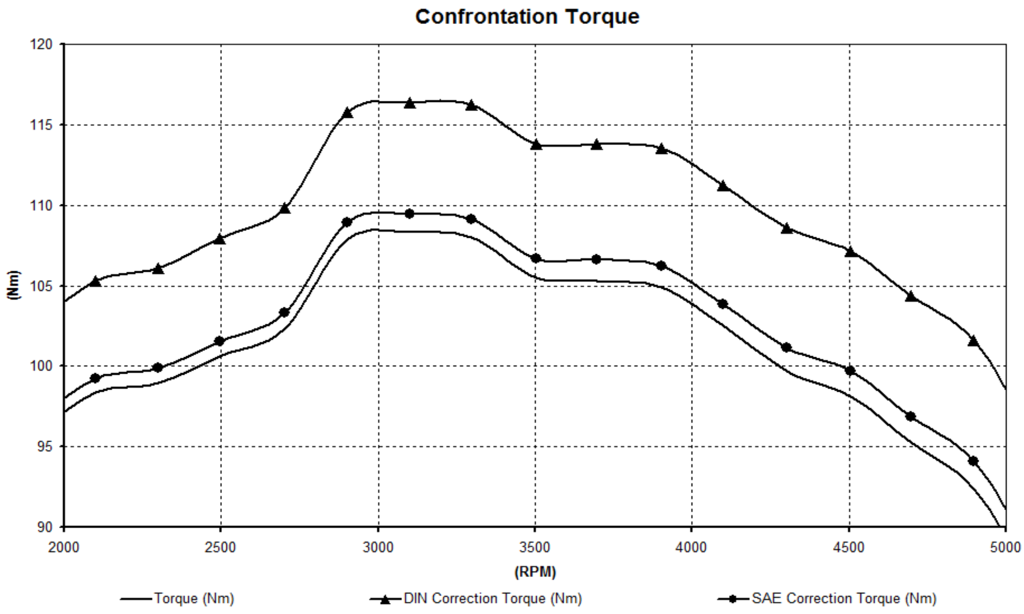

Fig.3 Confrontation of measured and corrected torque (DIN, SAE)

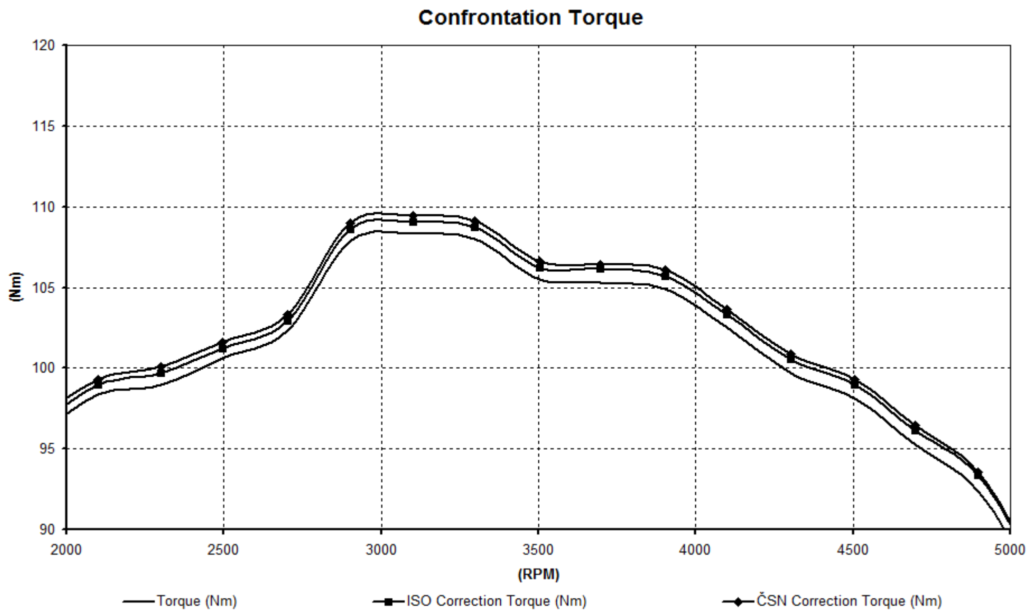

Fig.4 Confrontation of measured and corrected torque (ISO, ČSN)

Figures 5 and 6 illustrate the course of the measured dependence of the power on engine speed (Power (kW)) and the corrected estimate pursuant to the standards. Other shown dependences illustrate the corrected characteristics identified according to the names of standards (DIN, SAE, ISO, ČSN).

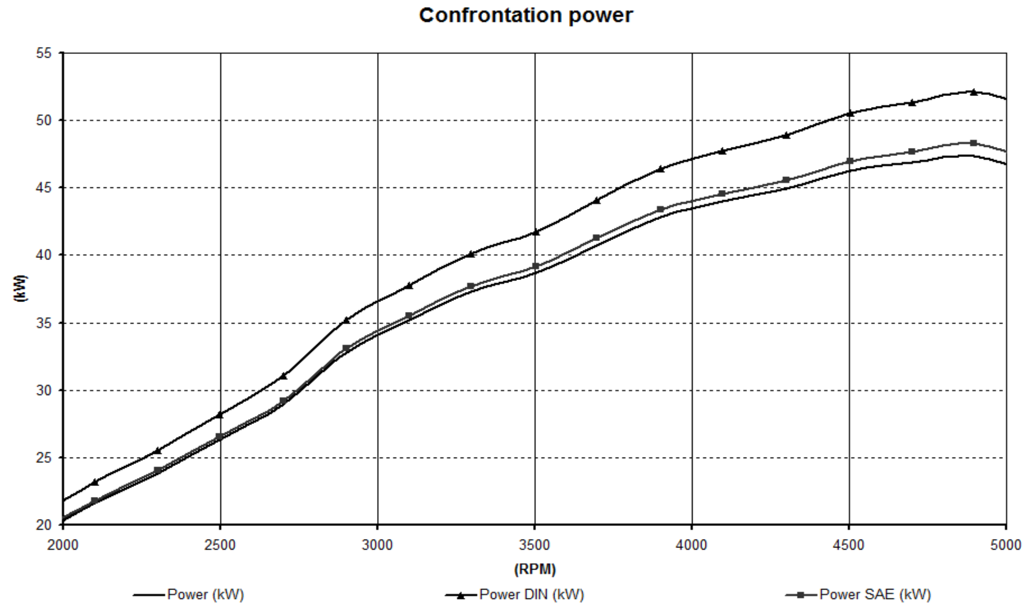

Fig.5 Confrontation of measured and corrected power (DIN, SAE)

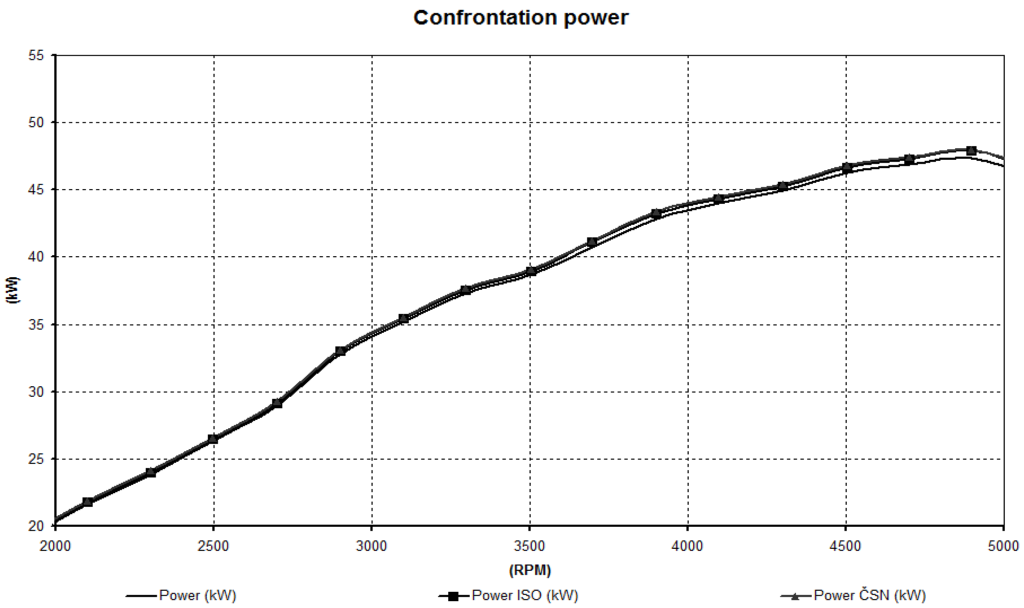

Fig.6 Confrontation of measured and corrected power (ISO, ČSN)

3 CONCLUSIONS

The article provides a partial description of issues related to braking and the combustion engines measurement. Main section deals with the customization of corrected output channels of a particular measuring system, i.e. the SuperFlow SF-902 system. The following paragraphs summarize the achieved results.

The manufacturer of the hydrodynamic engine brake does not offer power corrections pursuant to the ISO and ČSN standards as part of its program. Therefore, the output channels correction pursuant to the ISO and ČSN standards could constitute an advantage. This adjustment option was based on the requirement to standardize measurements for the commonly used Czech standards.

Evaluation of the measured data shows parallels among the SAE, ISO and ČSN corrections. Notably different were only the values corrected pursuant to DIN. According to this standard, the torque value was increased by an average of 7.8%. It should be noted, that further comparative measurements have to be carried out under different atmospheric conditions to provide a thorough analysis, after which conclusions can be made regarding the comparison of individual standardized correction methods.

The adjustments we made pointed out clear advantages of a modified measurement system. The scope of measurement options was expanded to include power correction pursuant to the ISO 1585 and the ČSN 30 2008 standards. Adjustment possibilities for the WinDyn program equipment were mapped and progress was achieved in terms of standardizing the Laboratory of Engine Testing at the Institute of Progressive Technologies for Automotive Industry.

REFERENCES

[1] JOHN DINKEL. *Chassis Dynamometer.* 2000. Road and Track Illustrated Automotive Dictionary, (Bentley Publishers)

[2] *The History of the Automobile - Gas Engines*. 2009. About.com. http://inventors.about.com/library/weekly/aacarsgasa.htm?rd=1. Retrieved 2009-10-19

[3] FRANTIŠEK VLK. *Zkoušení a diagnostika motorových vozidel*. 2001. Nakladatelství vlk

[4] *Manual 1100AXconsole SF-902.* 2007. vol.3. SuperFlow Tech. Group

[5] ISO. *Road Vehicles, Engine Test Code, Net Power.* 1992. ISO 1585, International Organization for Standardization.

[6] HEYWOOD, J.B. *Internal Combustion Engine Fundamentals*. 1989.vl.1. Bosch Gasoline-Engine Management, published by Robert Bosch GmbH

[7] GIACOSA, D. *Motori Endotermici.* vol.2. 1986. Ulrico Hoelpi Editore S.p.A., Milan.

[8] PULKRABEK, W.W. *Engineering Fundamentals of the Internal Combustion Engine*. 1997. Prentice Hall, Inc.

[9] REDSELL, M., LUCAS, G.G., AND ASHFORD, N.J. *Factors Affecting Car Fuel Consumption.* Vol. 207. 1993. Proc. Instn. Mechanical Engineers. N. D8, pp.895-904.

[10] TAYLOR, C.F. *The Internal Combustion Engine in Theory and Practice.* 1992. Vl. 1. The MIT Press, Second Edition, Revised, USA, 574 p.

[11] TSAO, K.C., AND MILLER, E.M. *Performance of Gasoline-Water Fuel in a Modified SI Engine.* 1984. SAE Technical Paper Series, SAE 841399, SAE.

[12] *Manual 1100A-WDUsers SF-902*, 2007, vol.3 SuperFlow Tech. Group

[13] DIN. *Automotive Engineering, Maximum Speed, Acceleration and Other Terms, Definitions and Tests.* 1986. DIN 70020, Deutsches Institut für Editore S.p.A., Milan.

[14] J. R. SODRÉ, J. of the Braz. *Soc. of Mech. Sci. & Eng. Programa de Engenharia Mecânica.* 2003. ABCM

[15] ČSN. *Motory automobilové zkoušky na brzdovém stanovišti.* 1980. ČSN 30 2008, Vydavatelství Úřadu pro normalizaci a měření, Praha