TDC Determination of IC Engine cranked by starter

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SHRNUTÍ

Obsahem článku je popis metody stanovení polohy horní úvratě (HU) pístu spalovacího motoru protáčeného startérem. Správně zjištěná poloha HU je nevyhnutná pro korektní indikaci tlaku ve válci zkoušeného motoru. Zkoušený motor je osazen na stavu, kde není možné protáčet motorem pomocí dynamometru. Jedná se o 4-válcový zážehový motor s využitím pro malou kogenerační jednotku. Měření se uskutečnili na zkušebním stavu, který byl vybaven tzv. on-line indikací.

KLÍČOVÁ SLOVA

Indikace tlaku ve válci, určení horní úvratě pístu, protáčení klikovým hřídelem

ABSTRACT

This article describes a method of position TDC determination of internal combustion engine. The engine crankshaft is cranking by starter. Rightly determined TDC is necessary for correctly in-cylinder pressure indicating. Examinated engine is on the test bed, where is not allowed to crank engine crankshaft by dynamometer in motory mode. Measurement unit is 4-stroke, spark-ignition engine for using in a small cogeneration unit. The experiments were performed on a test bed. On the test bed was used so-called On-line in-cylinder pressure indicating.

KEYWORDS

In-cylinder pressure indicating, determination of TDC, engine crankshaft cranking

1. INTRODUCTION

Exactly determination of Top Dead Centre (next TDC only) position of piston is necessary for correct in-cylinder pressure recording. The record of in-cylinder pressure pattern and its evaluation is one of the most powerful means for experimental optimisation of internal combustion engines. Incorrect TDC position produces deficiency in-cylinder pressure values permanently with regard to the crankshaft rotation. So it makes deficiency in-cylinder temperature evaluation and other thermodynamic magnitudes and courses (for example in Rate-of-Heat-Release (next ROHR only) courses).
There were many methods developed for determination of TDC position during the time. In principle, it is possible to divide these methods in two groups:

- static (engine is stopped)
- dynamic (engine is running)

In the author's laboratory was developed so-called On-line in-cylinder pressure indicating in the last time. This means that the in-cylinder pressure indicating as well as necessary data evaluation (top and minimal values of in-cylinder pressure and IMEP) are in progress almost in real time. These values are displaying on the screen of monitor. So operating personnel has view about the in-cylinder pressure and its course during test of the engine on the test bed.
Base on that, it was chosen the dynamical determination method of TDC position.

TDC position is determined on engine which crankshaft is cranked by foreign source. The combustion is off. A dynamometer with possibility to crank engine crankshaft is necessary instrument for determination of TDC by on-line in-pressure indicating.
Other solution of engine cranking without combustion is necessary in contrary case. For example: the test bed will be equip with electric motor. In this case it must be enough mounting space for electric motor on the test bed. It is necessary, however, to solve the disconnection between electric motor and engine crankshaft in state of engine with combustion.

Examinated engine is on the test bed, where is not allowed to crank engine crankshaft by dynamometer. Engine cranking by its own starter is the other possibility to solve this problem. In this case it must be determinate a progress, that will be guarantee the sufficient accuracy and authenticity of position TDC. There is a problem, however, in case engine cranking by starter – engine is cranking slowly and non-equally.
And just description of this progress (method) is contents of this article.

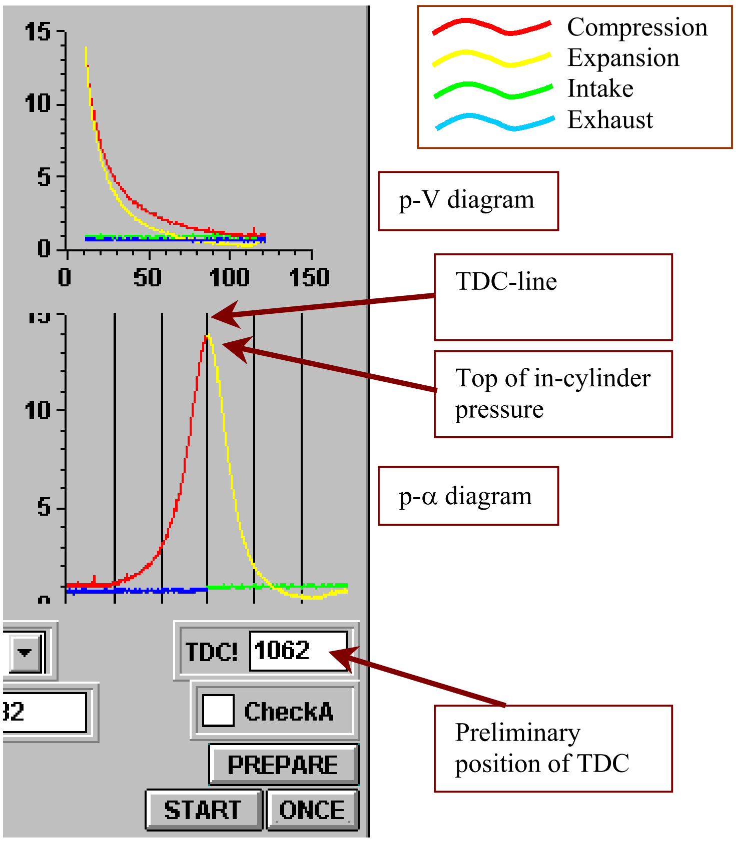

Figure 1: Determination of preliminary value of TDC by On-line indicating.
Obrázek 1: Stanovení předběžné hodnoty HU pomocí on-line indikace.

2. DETERMINATION OF PRELIMINARY TDC POSITION

In the article the in-cylinder pressure recording is considered as a standard part of experimental activity which is exploited continuously during the whole process of experimental research on an engine test bed. For this purpose examinated engine is equipped permanently with cooled pressure transducer and an angle encoder (Incremental Rotary Encoder, next IRC only) is permanently connected through a spring disc-type coupling at the front end of the crankshaft.
At first, cold examinated engine is cranking by starter. In this phase, revolution of engine crankshaft is very low (about 250 min^{-1}). This fact has a consequence the big losses of suck air from combustion

chamber around the piston assembly. For maximal elimination of this phenomena engine is cranking with widely opened throttle (next W.O.T. only).
In this first step the preliminary TDC position is determined. It is determined by special software ITI-ONL [1]. The preliminary TDC position is determined on the base of top in-cylinder pressure position with regard to the TDC line in p-α diagram in the window of ITI-ONL, Figure 1. In this phase about 10 cycles of indicated cylinder is recording on the harddisk of indicating computer. These data will be serve for secondary evaluation (not on-line).
From the previous experiments on this engine was found out that the piston assembly reach in warm up state better tightness. In this engine temperature state it is possible to obtain less losses of suck air in combustion chamber around the piston assembly as well as less distortion of in-cylinder pressure course.
Therefore, at second, engine is started and warming up on the operating temperature. Then is engine stopped. Warm up examinated engine is cranking by starter. In this phase, revolution of engine crankshaft is a bit higher (about 350 ÷ 400 min^{-1}). For maximal elimination of suck air losses from combustion chamber, engine is cranking with W.O.T. About 10 cycles of indicated cylinder is recording by program ITI-ONL. These data will be serve for secondary evaluation (not on-line) for determination of finally TDC position.

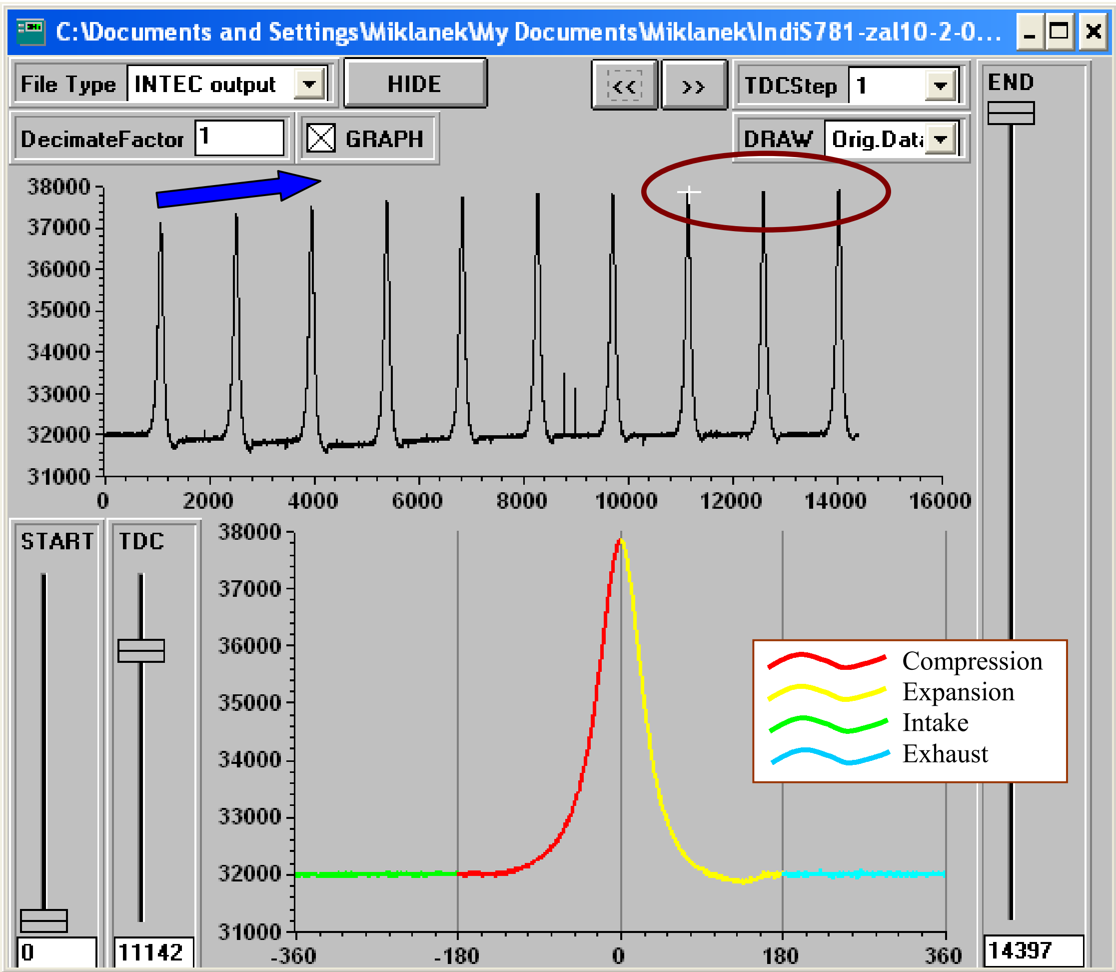

Figure 2: In-cylinder pressure courses during 10 cycles of indicated cylinder.
Obrázek 2: Průběhy tlaku ve válci během 10-ti oběhů indikovaného válce.

3. DETERMINATION OF FINALLY TDC POSITION

Data from in-cylinder pressure indicating of warming up engine serve for determination of finally TDC position. Special software INTEC [2] is used for evaluation of data from 10 cycles of indicated cylinder. Measured courses of in-cylinder pressure are corrected. Some false samples are deleted (these samples were triggered by an EMC problem, probably caused by the engine spark ignition system) by procedure as described in [3]. Next, measured data are corrected by software INTEC as long as the logical courses of ROHR and Relative Amount of Heat Transfer Through the Walls are obtained.

The amplificated original output voltage from pressure transducer of indicated cylinder is plotted by a black line, in the top part of the window in Figure 2. It is visible from this course that from the first to sixth or seventh cycle – the whole system (engine and the rotating parts of dynamometer) have been started up (it is depicted in Figure 2 by arrow). During these six or seven cycles the magnitudes of in-cylinder pressure are different at the end of exhaust stroke of piston and at the beginning of intake stroke (Figure 3a). Contrary, the courses in-cylinder pressure in the last three cycles are almost identical (it is depicted in Figure 2 by ellipse). During these cycles the magnitudes of in-cylinder pressure are almost identical at the end of exhaust stroke of piston and at the beginning of intake stroke (see Figure 3b).

On base this piece of knowledge the last three cycles regarded as usable for determination of finally TDC position. The courses from the semifinal cycle were chosen for the determination of finally TDC position.

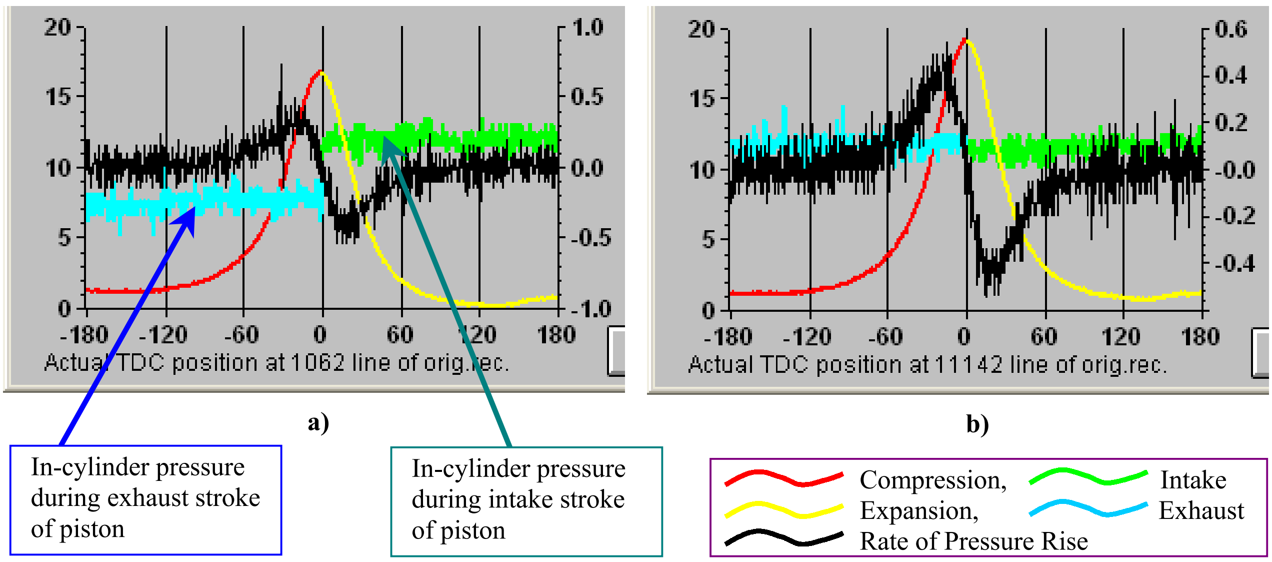

Figure 3: In-cylinder pressure courses during 4 strokes of piston.
Obrázek 3: Průběhy tlaku ve válci během 4 zdvihů pístu.

Finally TDC position is determined on the base of in-cylinder pressure courses and evaluated in-cylinder temperature courses (see Figure 4). The TDC position can be changed by cursor. The TDC position is changed by the number of samples, that corresponded with the samples from IRC. The change of one sample = the change of TDC position in 0.5° revolving of crankshaft.

The target is to find such position of cursor (and so the IRC sample too) that the curves of in-cylinder pressure were side by side, as near as possible in the area of top point. And next, the curves of in-cylinder temperature should couple in area of top temperatures with a sharp peak (see Figure 5). Obtuse peak in area of top temperatures is consequence of late TDC position with regard to really TDC of piston, Figure 4a. Loop in area of top temperatures is consequence of early TDC position with regard to really TDC of piston, see Figure 4b.

On the Figure 5 are depicted the courses in-cylinder pressure and in-cylinder temperature (p-V and T-V courses) at the chosen finally TDC position. The number under cursor means, how many samples are add or subtract to the value of the preliminary TDC position.

This way it is possible to determine the finally TDC position with sensitivity ± 1 sample (± 0,5 ° revolving of crankshaft).

Data from 10 cycles of indicated cylinder in cold engine temperature state are in this phase informative. They serve for appropriate confrontation of preliminary TDC position of engine in cold state and finally TDC position. The differences are in interval from 1 to 2 samples.

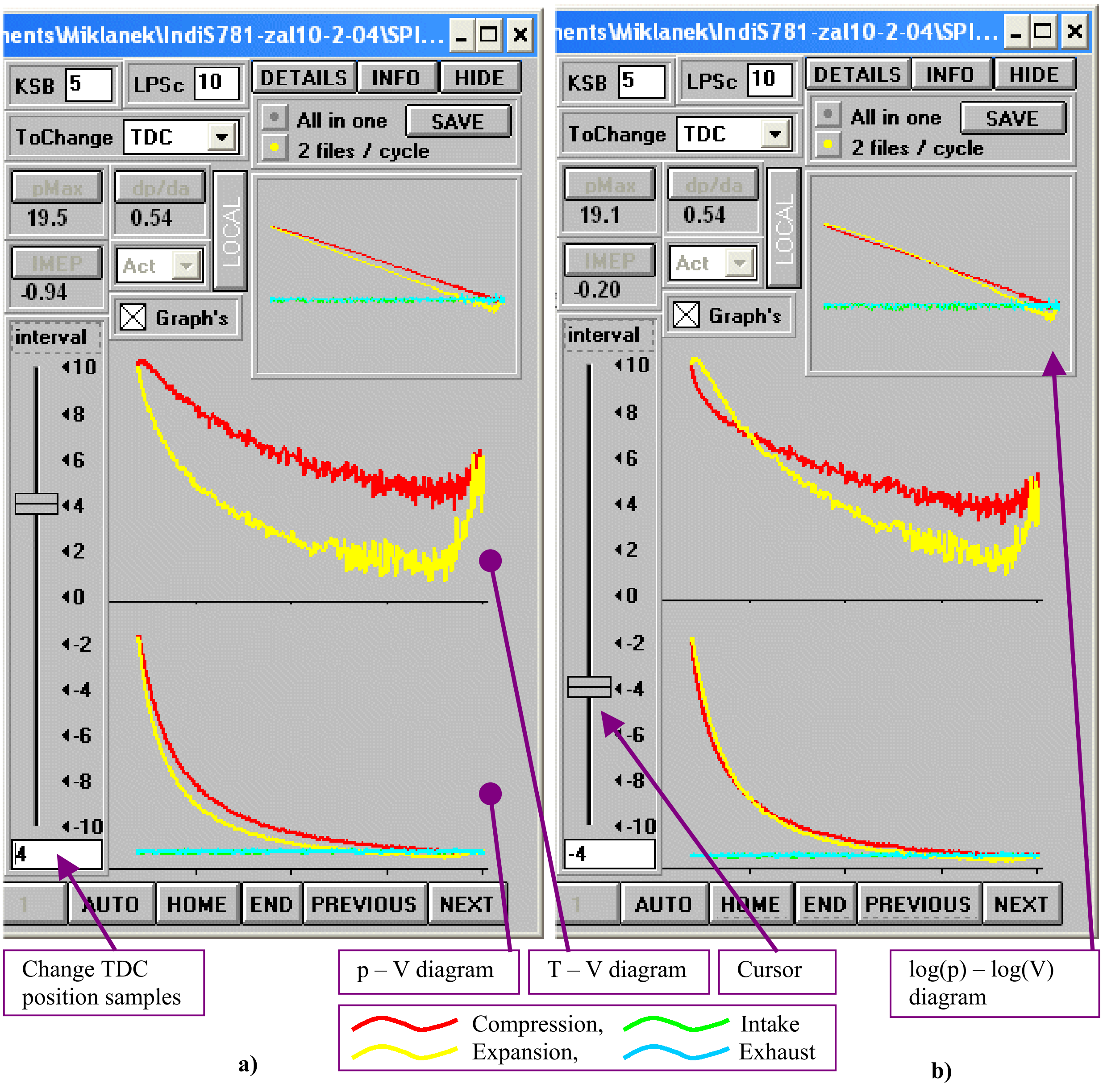

Figure 4: Changes of in-cylinder pressure and temperature courses by change of TDC position samples.
Obrázek 4: Změny v průběhy tlaku a teploty ve válci změnou polohy značky HU.

4. VERIFICATION OF THE FINALLY TDC POSITION

A regulation characteristic is necessary to perform with examined engine for verification of the finally TDC position. Characteristic is performed by maximum loaded engine at the constant RPM (e.g. 3000 min^{-1}). Regulated magnitude is pre-ignition angle (α_{1Z}). The values of pre-ignition angle were chosen 37°, 30°, 25°, 20° and 15° befor TDC. So the regulation characteristic consists from 5 points.

Data from engine and the whole test bed are acquired during the measurement by the data acquisition system (DAQ) that is used on the engine test bed. About one hundred cycles were recorded at the each point of characteristic by software ITI-ONL. After the finish of measurement, the data in-cylinder pressure indicating are analysed. An average p-V diagram is evaluated from one hundred recorded cycles of indicated cylinder for each point of measured characteristic.

Special software INTECgr [4] was developed for the evaluation of averaged p-V diagrams from measured points of arbitrary characteristic. The courses of IMEP and BMEP are evaluated by software INTECgr as well as the courses of in-cylinder pressure, in-cylinder temperature and Normalized Heat Release (next Qn only), Figure 6. These courses are criteria for verification of finally TDC position.

If the courses of IMEP and BMEP are logical with regard to their maximal and minimal value, and if the courses Qn, pCyl and Tcyl are logical with regard to chosen pre-ignition angle too, then it is possible to declare the finally TDC position as rightly determined TDC position.

In a contrary case it is necessary to find other finally TDC position and verify it again (by regulation characteristic).

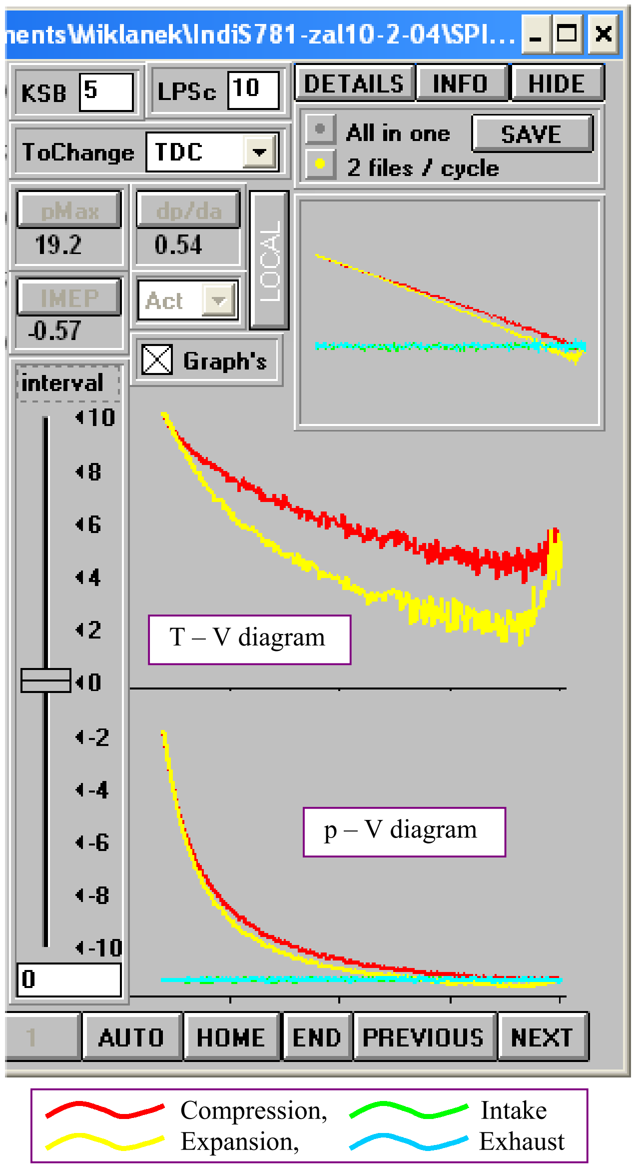

Figure 5: Choose of the finally TDC position.
Obrázek 5: Zvolená finální hodnota HU.

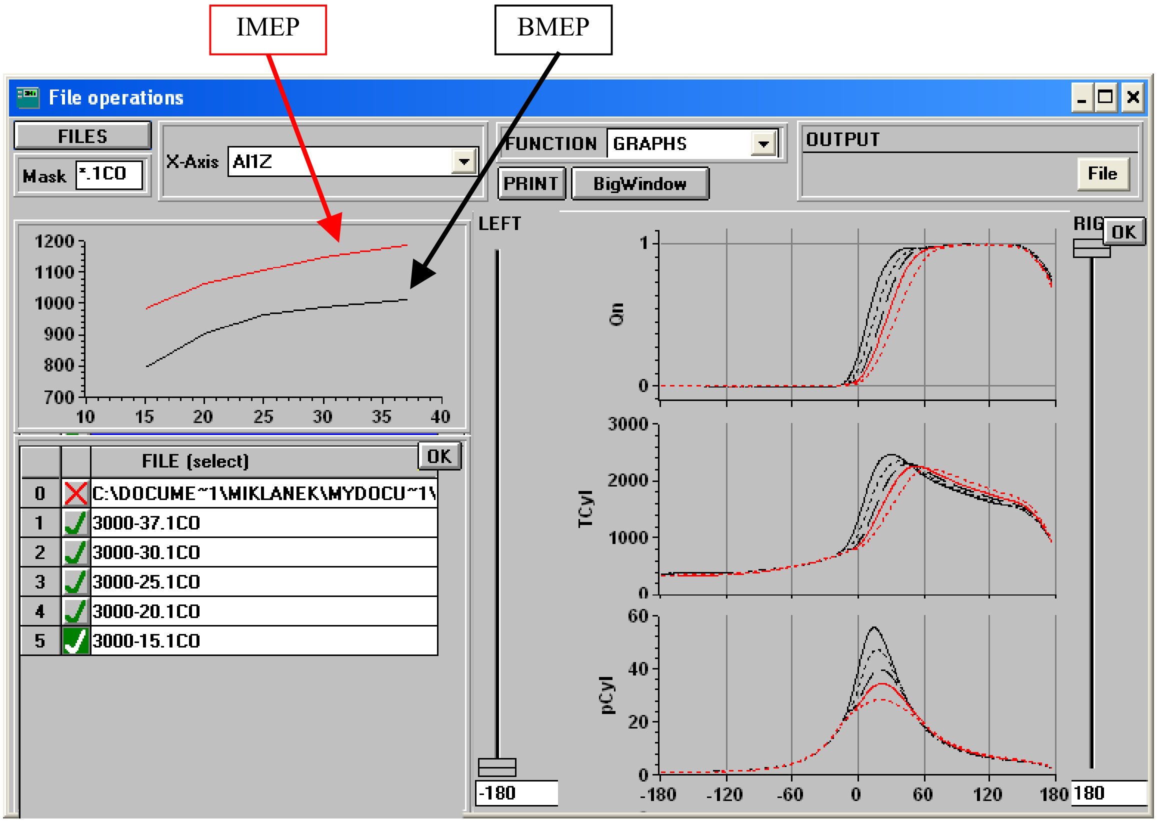

Figure 6: Verification of the TDC position by software INTECgr.
Obrázek 6: Ověření HU programem INTECgr.

5. CONCLUSION

For the determination of TDC position of engine cranking by own starter, it is necessary to solve at least two kinds of problems. It is a small revolution of engine crankshaft, which causes the big losses of suck air from combustion chamber around the piston assembly. Then it is a non-uniform cranking of engine crankshaft, which complicated determination of right TDC position.
In this article was described a method that eliminates above complications and it can be determined the authentic TDC position of engine cranking by own starter.
This method was verified at the Josef Bozek Research Centre.

6. ACKNOWLEDGEMENT

This research has been supported by grant: CEZ J04/98: 212 2 00009. The support and collaboration is gratefully acknowledged.

LIST OF NOTATIONS AND ABBREVIATIONS

BMEP	Brake mean effective pressure [Pa];	**ROHR**	Rate of heat release [-];
DAQ	Data acquisition system;	**RPM**	Revolutions per minute [min^{-1}];
EMC	Electromagnetic compatibility;	**TDC**	Top dead centre;
IMEP	Indicated mean effective pressure [Pa];	**TCyl**	Temperature of charge in cylinder [°C];
IRC	Incremental rotary encoder;	**V**	Cylinder volume [m^3];
pCyl	Pressure of charge in cylinder [Pa];	**W.O.T.**	Widely opened throttle;
Qn	Normalized heat release [-];	α	Crankshaft angle[°];

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