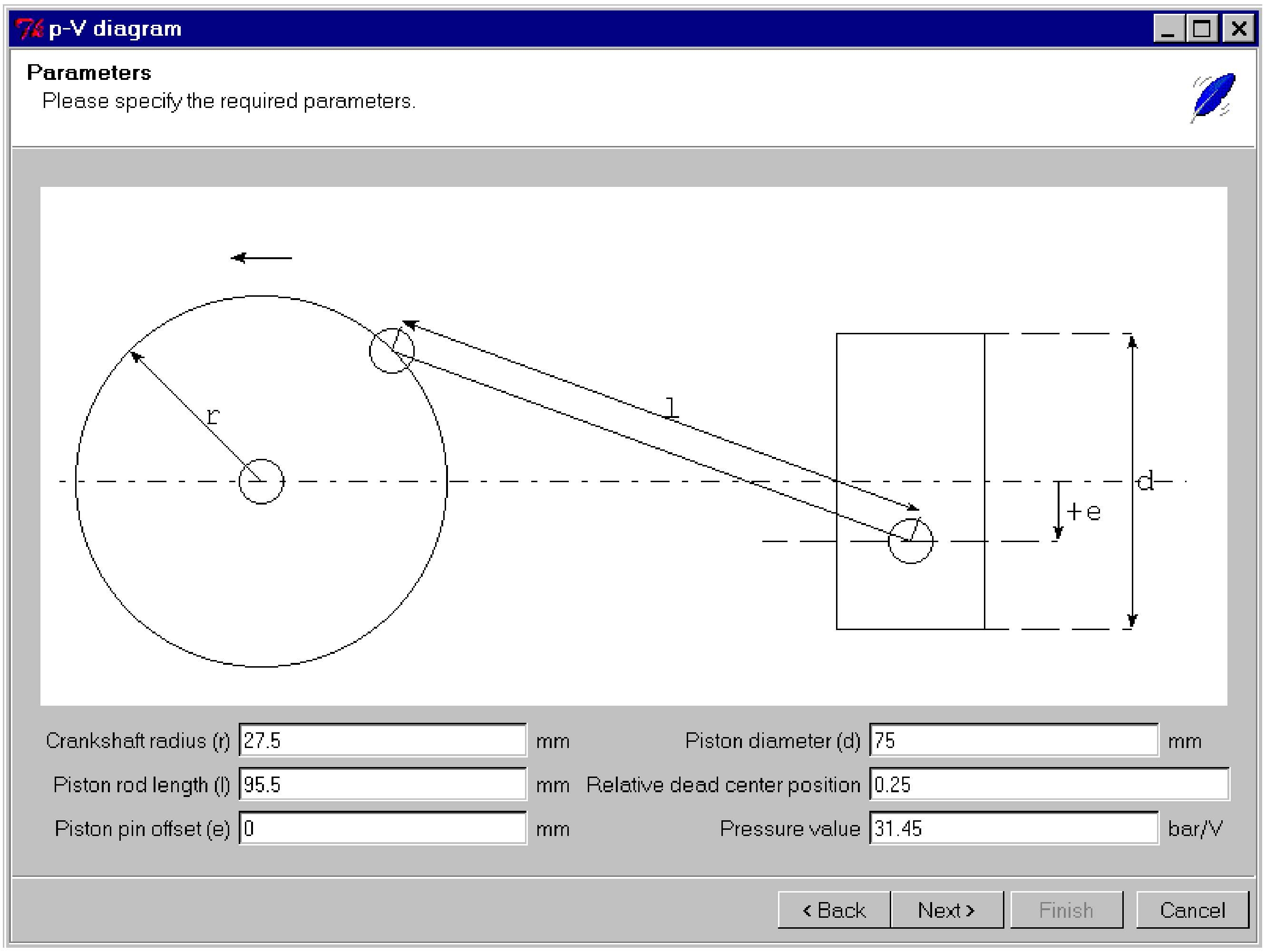
Method and equipment for measuring the cylinder pressure in piston machines

PicopV 1.0

for determination of p-V-diagrams with DiaW - Diagram for Windows



Picture 1

Application

In piston machines like pumps, compressors, and engines with internal or external combustion with one or more pistons a gas or a fluid is pressing onto the piston(s). When a piston moves, it delivers or consumes mechanical work. Methods and equipment for determination of this work are described in the following.

During one cycle of operation of a piston machine every piston oscillates one or two times, i. e. it makes 2 or 4 strokes. Motion of the piston varies the volume of the chamber formed by the cylinder and the piston and thus of the gas contained therein. .

In the science of thermodynamics the behavior of a certain constant mass of gas during variation of its volume is described by the p-V diagram showing the pressure as a function of the volume:

$$p = f(V)$$

This function depends on further conditions, especially on the flow of heat into or out of the gas during variation of the volume.

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10.851/3 gb   Picture 2
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Spark ignition engine

p-V diagram

Crankshaft radius: 40.7 mm
Piston rod length: 137.0 mm
Piston pin offset: 0.0 mm
Piston diameter: 79.0 mm
Pressure value: 29.94 bar/V
Relative dead center position: 0.5683

Computed Work (this measurement): :
406.6 J
Average Work (last 47 measurements):
402.1 J

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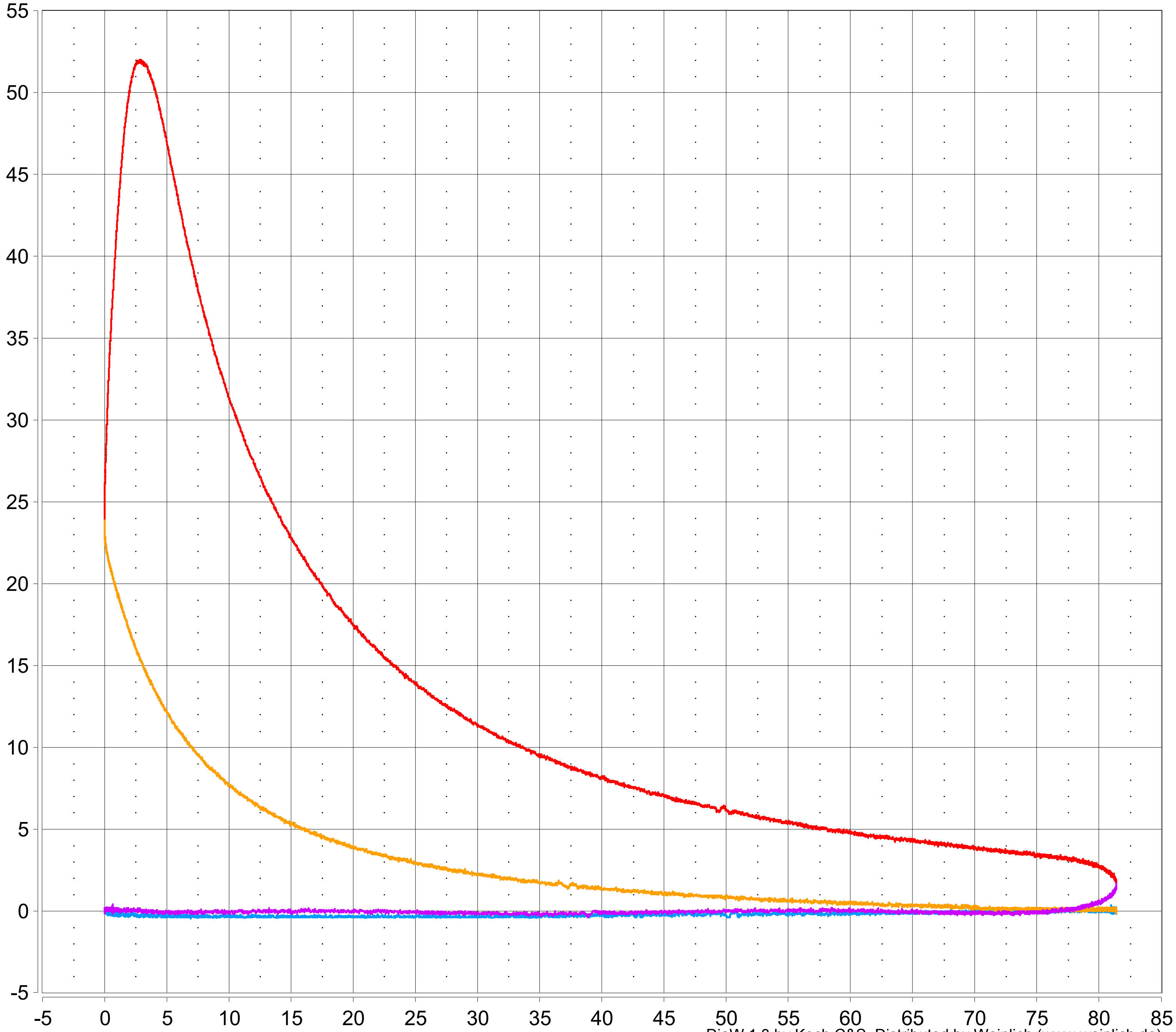
10851b2n X: s/mm Piston position
1: p/bar aspiration
2: p/bar compression
3: p/bar combustion, expansion
4: p/bar exhaust



DiaW 1.3 by Koch C&S. Distributed by Weinlich (www.weinlich.de)

In case the volume of the gas is decreased (the gas is compressed), the gas absorbs mechanical work.

In case the gas is compressed and then expanded again to the initial volume, but the pressure is e. g. lower during compression than during the following expansion, the functional curves p = f(V) are different for compression and expansion and form an open loop.

Because in a piston machine the piston is during compression and expansion the moving part of the wall enclosing the gas, the piston delivers work during compression to the gas and absorbs work during expansion from the gas.

However, a p-V diagram describes the thermodynamic behavior of a gas only as long, as the mass of gas in the considered volume remains constant, i. e. as long as the cylinder remains closed, e. g. in picture 2 only during compression and during combustion and expansion only until the opening of the exhaust valve, but not during the change of gas through the valves for inlet and exhaust.

In practice the cylinder pressure p is determined as a function of the piston position „s“ as shown on picture 2.

The pressure p multiplied by the area A of the piston is the force F pressing onto the piston:

$$p \times A = F$$

and variation of the piston position s multiplied by the force F is the work W delivered or absorbed by the piston

$$F \times \Delta s = W$$

On the other hand variation of the piston position s multiplied by the area A of the piston is the variation of the volume V

$$\Delta s \times A = \Delta V$$

and variation of the volume multiplied by the pressure is the work delivered or absorbed by the piston

$$\Delta V \times p = W$$

As the pressure p is not constant, but depends on the volume, the integral of

p = f(V) over V

must be determined.

As the area A of the piston is constant, the integral of

p = f(s) over s

can be determined and then can be multiplied by the piston area A for this purpose.

This means:
It is possible to determine on a paper sheet showing a diagram p = f(s) the area below the pressure curve and to multiply this by the scale factors of the diagram and by the piston area in order to get the work.
In picture 2 the area under the curve „compression“ is proportional to the work delivered from the piston into the gas and the area under the curve „combustion, expansion“ is proportional to the work delivered from the gas to the piston.

The area between both curves is the difference between both a. m. areas and thus proportional to the work, which the cycle consisting of the piston strokes „compression“ and „combustion, expansion“ has delivered to the piston.

Accordingly the small area between the curves for exhaust and aspiration is proportional to the work required by that cycle.

Both open loops are connected at their ends to each other and form the 4-stroke process.

The 2-stroke process consists of only 2 functional curves for p = f(s) in one closed loop.

In the following a diagram with functional curves for p = f(s) is called „p-V diagram“, too, for simplification.

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Measuring technology

In the past and partly still today the cylinder pressure depending on the piston position is measured on slowly running piston machines with directly accessible piston position by x-y recorders directly actuated by the motion of the piston and by the pressure. These recorders are called „engine indicators“, the diagram produced by these recorders is called „indicator diagram“, and the quantities effective at the piston are called accordingly „indicated pressure“, „indicated power or performance“, and „indicated work“.

Several reasons do no more allow application of mechanical engine indicators in most of all cases:

Movements of the pistons and pressure variations are too fast. Moreover the frequency of pressure variations has increased much more than the frequency of piston motion, because the internal combustion can produce pressure oscillation of high frequency („knocking“).

The diagram drawn on a paper by the engine indicator is not well suited for automatic data processing.

Today most of all machines with pistons transform the oscillation of the pistons into rotation of a crank shaft, but the pistons themselves are only seldom accessible directly during operation.

Because of the above reasons an equipment of today for production of the p-V-diagram is different from the mainly historical engine indicator as follows:

The pressure is measured by a piezo-electric pressure sensor.

Instead of the position of the piston the angular position of the crankshaft is measured by an incremental pick-up (resolver) with sufficiently high resolution.

It is usual to trigger the memorization of the measured value of pressure with every step or every n-th step of the resolver.

This state of the art has disadvantages:

1. The position of the piston must be calculated from the angular position of the crankshaft.

2. Coupling a resolver to the crankshaft is expensive and can be difficult.

3. The sampling rate of memorization is proportional to rotary speed of the machine. This is non-favourable for studying oscillations of which the frequency does not depend on the rotary speed of the machine, because if a certain number of measurements per revolution is specified, the sampling rate can become too low in relation to the frequency of the interesting oscillation in the lower speed range of the machine.

Indicator control and user's program „PicopV"

Disadvantage no. 1 is no more really important thanks to automatic data processing. Also the user's program „PicopV" described herein transforms the memorized function p = f(angle φ) into the function p = f(s proportional ΔV) and calculates the indicated work. For this purpose the user can input the necessary data about geometry and cylinder pressure measuring chain (see picture 1).

Furthermore the automatic output of the results of „PicopV" to the user's program „DiaW - Diagram for Windows" offers to the user comfortable possibilities of presentation on the screen and of editing a printed report (see picture 2).

The disadvantages no. 2 and 3 are avoided by the combination of the indicator control with the user's program „PicopV".

This combination allows to use a much more coarse division of the rotation, normally the toothing of the flywheel, instead of a resolver. Provided a sufficiently high sampling rate and an adequate capacity of memory this method requires no compromise concerning accuracy.

Instead of the resolver two simple pick-ups are sufficient, one sensing an index mark indicating the upper dead center of the crank drive and the other normally sensing the toothing of the flywheel.

However, if desired or necessary, also a usual resolver instead of the two sensors can be used and connected to the indicator control.

The PC user's software "PicopV" controls continuously together with the indicator control acquisition of data for inividual working cycles, forms from them p-V diagrams, evaluates the latter and calculates an average of indicated work of the evaluated working cycles. This average is important with respect to the differences between the individual working cycles even at constant load of a combustion engine.

„PicopV" displays graphically for the evaluated working cycles:

versus time signals for the pressure and information belonging to about the rotary crankshaft position,
the p-V diagram belonging to,
and the alteration of the indicated work of the evaluated cycles.

The repeating frequency of acquisition and evaluation of working cycles by „PicopV" depends on the capacity of the PC.

The report in picture 2 is produced using „PicopV".

Version 1.0 of „PicopV" is suitable for one cylinder of a four stroke piston machine with simple crankshaft, even with piston pin offset. Other versions are available with delay.

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