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Modular Instrumentation System for Real-Time Measurements and Control on Reciprocating Engines

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f this modular instrumentation system are the real-time computation of parameters and t

a large number of consecutive cycles in

EP and MFBR, other instruments have been developed to provide the following functions

angle to sweep the oscilloscope horizontal axis and generate pressure- volume diagrams

100- or

n a computation of the mean and the standard deviation of the sample.

e crankshaft angle where an event such as ignition, injection,

or peak pressure point occurs.

the peak-per-cycle value of a parameter such as cylinder

or injection pressure.

Generate the average curve of a parameter of

consecutive cycles, such as average pressure or

average MFBR curves.

mands of controlled timing and duration to control ignition, injection,

or

ne operation. A modular plug-in concept was adopted to increase the flexibility

oped for reciprocating engines. Among the parameters measured are the indicated mean

erformed from measured cylinder pressure and crankshaft angle and are available in rea

gine. Data are displayed in bargraph form and the mean and the standard deviation are

Introduction

e research program is to develop a computer model for the Otto cycle that will predict the

ped primarily to provide input data to generate empirical equations

nd to verify its results. The instrumentation system provides

a real-time measurement

on of key combustion parameters and displays the results in

e (MFBR). IMEP is the work per unit of displacement volume performed during an engine

njection) and combustion and the combustion time

een recognized as important indicators of combustion. They have typically been determi

of

hotographs. The reduction of photographed data has not been automated and does no

addition, high-speed recording with postrun computer reduction is also being used. Neither

l the parameters are computed and displayed as

ed by the variations in engine operating speed, both steady state and transient. Time-dor

different engine operating speeds. Angular position analysis eliminates engine speed vari

a

an absolute position optical shaft encoder directly coupled to the crankshaft. The encode

0.35"

ariation in a parameter from one cycle to another under equal engine operating conditi

module rack contains major power supply components (i.e., transformers, rectifiers, ar

parameter variations, the digital display is of the continuous-averaging type with a tim

ry engine cycle a serial digital output is produced by each module for use by the statistic

1.

Function Generator

and the instrumentation systems. This module performs several other operations, as il

2).

This code is desirable in that synchronization between the bits is easily obtained but is no

onverts the Gray code to a natural binary code. An extra bit is added to convert the

erate an analog signal proportional to the crackshaft angle. This analog signal is used a

8

peed and speed fluctuations. The display is actually 2048 discrete dots, a dot for each in

geometry and the crankshaft position. The cylinder volume, as a function of

atile read- only memory. In the function generator this memory is used as

al, which is used to generate pressure-volume diagram displays. A switch can select wh

e function generator are displaying engine speed and generating reference marks. Eng

er unit of time. Reference marks are generated every lo", with larger

2 7200

Bit

ry craokshafl-angle data to-anlog Linear sweep 4 converter

nder selection memory Digital- to-analog converter Volume signal

Angle decoder Timing marks

tal Engine time Counter base speed display Figure

2. - Block diagram of function generator.

marks at 90" and once per 720" to generate 8

erence points for the oscilloscope displays. The

and 90" marks are derived directly from the binary

nory used to store the volume signal. The sweep, volume signal, and reference marks

om a power supply in the function generator. The function generation module is shown

4.

Indicated Mean Effective Pressure

cated mean effective pressure can be used as a

measure of combustion efficiency. IMEP is a ton face during a single thermodynamic cycle, normalized by the cylinder displacement.

a

d parameter and has not generally been available as

be readily determined from a pressure-volume (P-V) diagram, as shown in figure

5. The area enclosed by the

ent of the work done by the engine. Area A1 represents negative work, or

rk done on the engine. The algebraic difference

lternatively be computed from an analysis of pressure-crankshaft-angle data. This has c

er of consecutive cycles that are not readily available from

P-V diagram analysis. In this instrument (refs.

2 and 3) IMEP is

EP is defined as the closed integral of the pressure-volume relationship in the cylinder d

= - +Pdv A1

VD Crankshaft angle, dq

Figure 3. - Function generator outouts.

Figure 4. - Function generator.

e displacement volume. This integral can be performed in the

8 domain by a change of variables:

IMEP = - [P[de)dB 1 '*O" dv

v, .H=O

the instrument this integral is approximated by a

summation of finite difference products: where

A0 =720"/n and n= 1024. The term AV/AB is

a function only of engine geometry and 0: m L

In

m a

.&

Intake m L

In

m a

.&

Intake

I I

TDC BDC

Volume

ssure -volume diagram. IMEP = Net WorklDisplaced volume -

(A2 - A1)IVp

where

V

A

R

r

e

vc volume cylinder area rod length

e crankshaft postion (measured from bottom dead center

(BDC))

clearance volume

AV -=A[-r sin e A0

red in a memory as is the function-generator volume signal. The computation of

pressure by the stored function and summing the products. The computation is perfor

1024 times during each engine cycle or at

approximately 0.7" increments of 8.

ument is shown in cycle the accumulator value, as an analog signal, is figure

and the to attain the high speed required. The pressure signal accumulator is reset for t

nterval. The during the computation are shown in figure 7. Figure

d with 7(a) is the absolute value, as an analog signal, of an adder-accumulator. At the e

gine AV/A8. These traces are shown for one 720" engine

Pressure transducer 1 Pressure I ,

transducer

lemory - Multiplier - Analog- converter encoder - IMEP accumulator Adder-

A A

Control and timing -

Figure 6. - Block diagram of IMEP instrument.

20 0 360 720 Crankshaft angle, deg (a) Absolute value

b) Absolute value of P(AVVIA9) versus crankshaft angle.

versus crankshafl angle. ,

0 350 720 Crankshaft angle,

dq

VIA9) Ld) Bargraph of 100 consecutive versus crankshaft angle. IMEP values.

10 psildivision. Figure 7.

- Signals during computation.

nter (TDC) of the combustion stroke in the center. The actual value of

g the second and fourth quadrants of the trace. The absolute value of

e would be negative during the second and fourth cycles. Figure 7(c) is the running sum

re acting on the other side of the piston. Including crankcase pressure would effectivel

7(b) and (c) to indicate negative work during the intake stroke. Figure 7(d) is a bargrap

MEP module but is formatted by the statistical signal processor module. The amplitude

a

his sample was taken near the lean limit (equivalence ratio,

s considerable variation in IMEP: The standard deviation was

22

he mean. The IMEP data have been verified by extensive

iagram analysis. (Agreement of the data has been

ding at 20 percent of full scale.) The module can be adapted to

emory (a plug-in component) and the calibration setting. The IMEP module is shown i

8.

indication of combustion efficiency, it gives little insight into the combustion process. Eve

P(AV/AB)

FBR) will indicate several characteristics of the combustion. The MFBR curve displays

crankshaft angle. The MFBR curve is shown in figure

ition delay is the interval between ignition and the crankshaft angle where

. The burn interval is defined as the interval between crankshaft angles where

engine cycle. Although some variation in the total mass burned is expected because o

6 ..~. C-77-583

Figure 8. - IMEP module. Pressure

50 psildivision - I

Crankshaft angle Figure

- Pressure and mass-fraction burn rate curves.

he IMEP instrument and also by using only pressure and crankshaft-angle information.

nced by Rasweiler and Withrow (ref.4). Basically, the pressure rise, or decrease, in

mponents. Piston motion will compress, or expand, the volume and cause

an additional pressure rise if any of the fuel mass was burned during the interval. The

@'@p+APb (7) where

ange during interval APp pressure change due to compression or ge due to mass burning Let Pi be the actual pressure at the end

i-1 be the pressure at the beginning of the interval. We can define

ressure Pi' that would be the pressure at the end

change was due to expansion or compression. Then it follows that expansion

ming a quasi-static adiabatic process, PV? =Constant where

y polytropic gas constant, Cp/C,

Then by backsubstitution or The mass burned during the interval proportional to the pr

eous cylinder volume at the end of the interval. Therefore L\M= k Vi(APb) (14)

where k is the constant of proportionality, or

~~4=k(')(Pi v-pi- 1 c- 1) c (1 5)

the last term will be abbreviated to A(PV7) in the following discussion.) The mass fra

M's. In the instrument (block diagram of figure

ressure duqng each 0 increment (0.35") is multiplied by

us interval. Any deviation is due to mass burning. The A(PV7) terms are multiplied by

V/Vr

ve. The computation is only valid when all valves are closed and is therefore performed

a -45" to 135"

interval about top dead center. The

term is stored in a memory and multiplied by P

in a multiplying digital-to-analog converter. A

ator (ref.5) determines A(PV7). This is digitally multiplied by

ory, and summed. The MFBR curve is then normalized to determine the

d 90-percent points. The delay between ignition and

percent mass burned and the interval between

10 and 90

nt mass burned are determined. The MFBR curve

e are not directly accounted for in the analysis but can be compensated for by changes i
e instrument. Results obtained by using the mass fraction burn rate instrument compar
of
kshaft-angle data. The MFBR instrument is shown in figure
11.

Statistical Signal Processor Module

tical signal processor module was designed to provide
a meaningful real-time display of
le in the system typically produces a measurement or computation for every cycle
g rpm, data are produced too rapidly for the operator to comprehend. For example, a
3000 rpm,
neasurements or computations are performed by
7 P Pressure transducer
Shaft position encoder Control and timing Figure
10. - Block diagram of MFBR instrument.
u .,
F'
c-77-34
Figure 11 - MFBR instrument.
cond. The digital displays on each module do provide an indication
tical sense, and provide no information as to the cyclic variations in the parameters.
ta from the various modules connected to it. Upon initiation of a sample command, th
in the module, each divided into an upper and lower partition. Thus data can be collect
he data are recalled from the memory and formatted into a bargraph display for each
of each bar is proportional to the parameter value for a particular engine cycle. The
of

cycle on the left. These bargraphs are displayed on an oscilloscope.

A block diagram

of the statistical signal processor module is

shown in figure 12.

lso processed by analog circuitry to produce the statistical mean and the standard devi

for the 100-

cle sample. A low-pass filter in Data LOW > pass Mean

in + Memory Data

-b

High pass + True rm

s

Digital- converter Memory

4

address 4

r to-analog 4 output multiplier * Analog Y-axis output

A

Oscillator Control logic Figure

2. - Block diagram of statistical display module.

ter is used to compute the standard deviation. The mean and the standard deviation a

channel is displayed on the readouts. However, all the mean and standard deviation valu

of the module rack

the standard deviation the statistical signal processor module also measures the ma

n and the standard deviation by using the same channel selector switch. All the maximu

ary recording. The statistical signal processor module is shown in figure

13.

Event Detector

tector module has been developed to measure the angle

ed primarily to determine the point at which ignition occurs. However, the design was ma

so that other events Standard deviation

Figure

13. - Statistical signal processor.

parameters such as pressures cross a selectable value from either direction, or, in conju

ximum or minimum value. The module accepts analog or digital inputs in the range

l is provided on the front panel to set the trigger level. A switch is provided

d to select whether the first or last crossing is detected. Additionally, a window 180" wide

to

ws parameters such as ignition timing to be determined for any one of the cylinders. Th

Peak Detector

to determine the maximum or minimum value of an analog input signal. A switch

he peak or valley mode of operation. In the peak detect mode an internal track-hold an

cycle. The amplifier is then placed in the track mode and will follow the input signal

es into the hold mode and retains the peak value at its output. A status output signal is

ill again track the input until a new (higher) peak is reached. Operation in the valley mod

the input until a minimum level is detected. As with the event detector

rement to portions of the 720" cycle. An additional switch position is used to disable the

entire cycle can be examined. The status output signal

peak value and the crackshaft-angle where the peak occurred can be measured. The

15.

Curve-Averaging Module

of prime concern. However, because of the cyclic variations in combustion, it is difficul

entative curve for a parameter. The curve- averaging module (ref.

2) was developed to provide a

ssive cycles and divides the output by 100 to obtain the average. The average curve is s
point approximation to a 720" curve, or it can be used
our- channel mode, averaging two or four separate curves
Event detector module. Figure 15. - Peak detector module.
10 Figure 16. - Curve-averaging module.
ule with 1024 or 512 points per curve. The input signal range is
f 10 volts. This module is shown
in figure 16.

Event Generator Module

various points in the engine cycle. Switches are provided on the front panel to set the ev
) on the compression stroke and the event duration
n each compression stroke of the engine. This allows for control of engines with up to

Concluding Remarks

e the performance of internal combustion engines has been hindered by
a
ustion process. Data from the combustion process have been tedious to obtain
of data reduction. This instrumentation system makes available the real-time calculatio
gine speed fluctuations. The modular concept allows flexibility in test system configuratio
25, 1980, 505-41.

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15. Supplementary Notes

16. Abstract

been developed for reciprocating engines. Among the parameters measured
mean effective pressure, or theoretical work per cycle, and the
er. These computations are performed from measured cylinder pressure and cranksha
real
ecutive-cycle sample is analyzed to reduce the effect of cyclic variations in the engine.
and the mean and the standard deviation are computed. Other instruments
are also described.

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