단기통 가솔린 엔진 배기단의 압력 변화에 관한 실험 및 수치해석

Computational and Experimental Analysis of Exhaust Pipe Pressure Distributions in a Single Cylinder Gasoline Engine

정효민 · 최석천 · 심규진 · 김세현 · 고대권 · 정한식

H. M. Jeong, S. C. Choi, K. J. Sim, S. H. Kim, D. K. Koh and H. S. Chung

Key Words: Method of Characteristics, Pressure Prediction, Compressible Flow, Pulsating Pressure, Exhaust Pipe

Abstract: 본 연구는 단기통 4행정 기관의 배기단의 형상에 따른 실험과 수치해석이 소개되었다. 흡·배기 밸브가 작동하고 있고, 주요한 배기단의 변수로는 배기단 직경이 적용이 되었다. 실험결과로는 배기단의 직경에 따라 배기 압력은 많은 영향을 받았는 것으로 나타났다. 배기단의 직경이 감소하였을 때, 배기압력파의 진폭과 파수가 증가되었다. 배기단의 직경이 증가 하였을 때, 배기압력파의 진폭이 감소하였다. 직경이 22mm 일 때의 소음의 주파수 분석이 16mm와 28mm 보다 진폭이 작게 나타났다.

Nomenclature

A	:	non dimensional speed of sound[a/a_{ref}]
a_{ref}	:	reference speed of sound[m/s]
bdc	:	bottom dead center
D	:	diameter of pipe[m]
evo	:	exhaust valve open
evc	:	exhaust valve close
F	:	cross section area of pipe[m^2]
ivo	:	intake valve open
ivc	:	intake valve close
N	:	engine revolution[rpm]
P	:	pressure of pipe[bar]
P_c	:	pressure of cylinder[bar]
tdc	:	top dead center
U	:	non dimensional velocity[u/a_{ref}]
u	:	gas velocity[m/s]
β	:	Rimann variable of characteristics
λ	:	Rimann variable of characteristics
k	:	ratio of specific heats, [C_p/C_v]
ρ	:	density[Kg/m^3]
θ	:	crank angle[°]
∅	:	nozzle area ratio[F_t/F]
cr	:	critical conditions
in	:	characteristic towards boundary
out	:	characteristic from boundary
t	:	throat condition

접수일 : 2004년 9월 30일

정효민(책임저자) : 경상대학교 기계항공공학 · 해양산업 연구소

E-mail : hmjeong@gsnu.ac.kr, Tel : 055-640-3184

최석천, 심규진, 김세현 : 경상대학교 대학원,정밀기계공학과

고대권 : 부경대학교 기계공학부

정한식: 경상대학교 기계항공공학부 · 해양산업연구소

1. INTRODUCTION

Recently, automotive emissions regulations are more severe by the Environmental Protection Agency (EPA), and many researchers have been concerned to acoustic performance for the intake and exhaust system. The radiated noise is caused by the acoustic behavior of the intake and exhaust pipe system and engine type etc. This is often dealt with in either the frequency domain or in the time domain analysis. The frequency domain analysis of mufflers is done by means of the transfer matrix method. The time domain modeling by means of characteristics is complete in itself.

But this model has some disadvantageous for the aero acoustic performance evaluation of the exhaust system. The research about new hybrid approach for predicting of noise radiation from engine exhaust system was suggested by Munjal(1). Also, the three point method were proved that the advantage of analytical simplicity and computational speed, and were as accurate as the boundary element method by Chu et al.(2)

The use of computer simulation techniques for the improvement of engine development processes has been rapidly expanding over the last decade. Computational methods in fact not only offer reliable predictions of the effect of geometrical modification on engine performance, thus reducing the number of prototypes and experimental tests required for engine optimization, but also allow a better understanding of the unsteady flow phenomena that occur during the gas exchange processes.(3-4) Moreover these techniques provide information on physical quantities which are difficult to measure, such as residual exhaust fraction, instantaneous exhaust and intake mass flow rates, etc.

The aim of this paper is therefore to provide the informations of pressure distributions and frequence characteristics by the computational and experimental techniques for the development of a high performance four-stroke motorcycle engine.

2. METHOD OF NUMERICAL ANALYSIS AND MODEL

2.1 METHOD OF NUMERICAL ANALYSIS

The one dimensional and unsteady compressive flow was assumed and the method of characteristic (MOC) was introduced for calculation in each side of intake and exhaust manifold. As the isentropic flow was assumed, the friction and heat transfer was not considered in this study, and the governing equations are constituted with of continuity, momentum and the characteristics that λ and β are given as followings:

$$\frac{\partial \rho}{\partial t} + \rho\frac{\partial u}{\partial x} + u\frac{\partial \rho}{\partial x} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial \rho}{\partial x} + \frac{1}{\rho} \cdot \frac{\partial P}{\partial x} = 0 \tag{2}$$

$$\lambda : \frac{dx}{dt} = u + a, \frac{du}{dt} = -\frac{k-1}{2} \tag{3}$$

$$\beta : \frac{dx}{dt} = u - a, \frac{du}{dt} = +\frac{k-1}{2} \tag{4}$$

2.2 BOUNDARY CONDITIONS

The length of intake and exhaust pipe were measured by the real motor cycle engine that was selected for standard numerical calculation model. The exhaust pipe diameter of the real motor cycle engine was d = 22mm. The boundary condition of intake and exhaust manifold for single cylinder 4-cycle engine are explained as the followings, and the method of characteristics was introduced for numerical analysis, and the main boundary conditions can be written as:

close end,

$$\lambda_{in} = \lambda_{out} \tag{5}$$

open end,

$$\lambda_{out} = 2 - \lambda_{in} \tag{6}$$

Subsonic flow,

$$U^2 = \left(\frac{2}{K-1}\right)^2 (\lambda_{in} - A) \tag{7}$$

Sonic flow,

$$\frac{U}{A} = \varnothing \left(\frac{A_t}{A}\right)_{cr}^{(k+1)/k-1)} \tag{8}$$

2.3 TESTED ENGINE AND THE CALCULATION MODEL OF EXHAUST PIPE

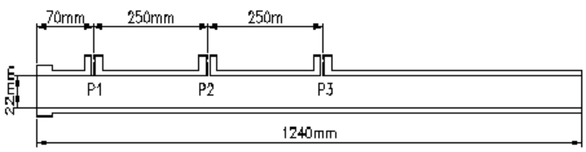

Fig. 1 Schematic diagram of experimental and numerical model for single cylinder engine

Table 1 Specifications of tested engine model

Specifications of numerical model	
Engine type	4-stroke, single cylinder
Engine displacement (cc)	124.1
Bore/Stroke(mm)	56.5/49.5
Connecting rod length (mm)	100
Intake valve open(°)	BTDC 10
Intake valve close(°)	ABDC 30
Exhaust valve open(°)	BBDC 41
Exhaust valve close(°)	ATDC 1
Compression ratio	9.5:1

The specifications of single cylinder 4 cycle engine are shown in Table 1. Figure 1 shows the experimental and numerical result points in exhaust pipe. The basic length of intake and exhaust pipe was selected from a real motor cycle engine, the exhaust pipe length and diameter were l 1,240mm and d 22mm which named standard type of exhaust pipe. The calculation mesh is a constant space grid and the numbers of mesh are one hundred. The temperature and pressure of ambient condition in numerical calculation model are 293 ^{o}K and 1 bar, respectively. The intake valve opening timing is 340° and the exhaust valve opening timing is 139° . The maximum value of intake valve area have wider than the exhaust valve, and the difference was the maximum intake value area has 21 % wider than the maximum exhaust valve area.

Fig. 2 Schematic diagram of various exhaust pipe geometries

Figure 2 shows various exhaust pipe geometries. The standard type of exhaust pipe is d = 22mm, an expanded pipe diameter was selected with d = 28mm and a reduced pipe diameter was selected with d = 16mm.

3. EXPERIMENTAL METHOD

2.1 EXPERIMENTAL PROCEDURE

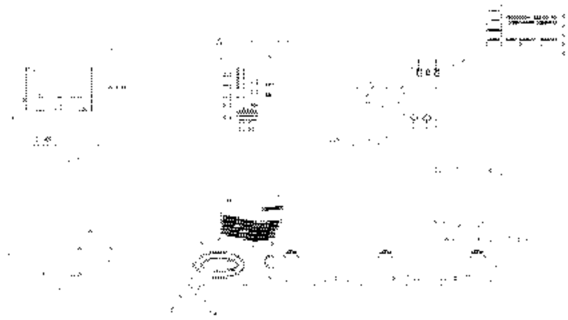

Fig. 3 Schematic diagram for experimental set up

Table 2 Experimental instruments

equipments name	type	manufacture
pressure sensor	4045A	Kistler Ins., Corp.
amplitude	5738	Kistler Ins., Corp.
bnc cables	4761A	Kistler Ins., Corp
cooling adapter	z511	Kistler Ins., Corp.
rotary encoder	e6c2-cwz3e	Omron Corp.
a/d board	pci 6013	N. I., Corp.
sound level equipment	lm 9600	Human Sci.
soft ware	lab-view6.1	N. I., Corp.

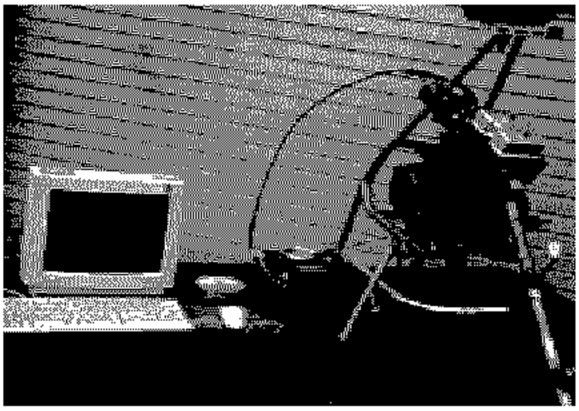

Photo 1 Photography of experimental model for single cylinder engine

Figure 3 and Photo 1 shows the schematic diagram and photograph of the experimental model for single cylinder engine. The standard type of exhaust pipe was applied as this experimental research. All of the experiments were carried out 10 times at every experimental position. Table 2 show the test equipments for experimental model.

The numerical results should be compared with the experimental results, which are required to assess the new engine development and reliability.

4. RESULTS AND DISCUSSIONS

Figure 5 shows the experimental results in the case of standard type at d = 22mm, l = 1,240mm and N = 1,000 rpm. The pressure

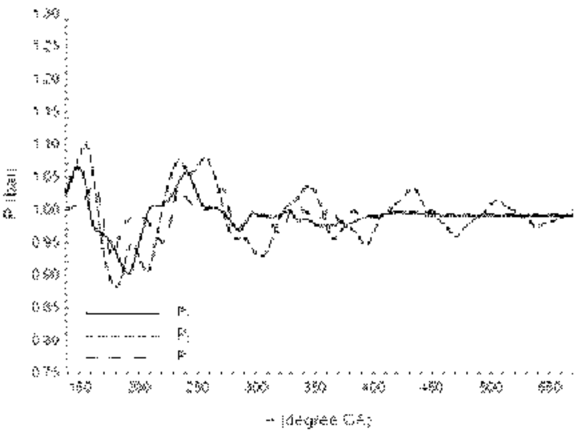

Fig. 4 Experimental result in case of d = 22 mm and N – 1,000 rpm at P_1, P_2 and P_3

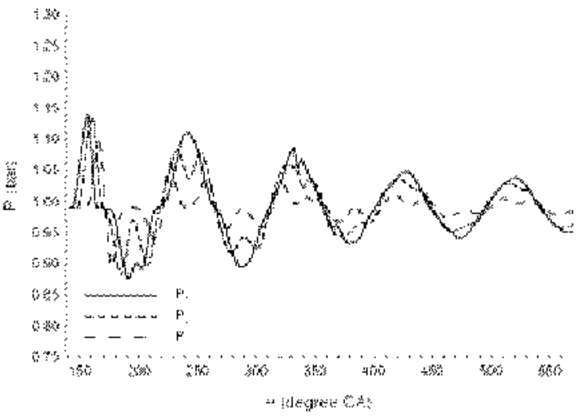

Fig. 5 Numerical result in case of d – 22mm and N – 1,000rpm at P_1, P_2 and P_3

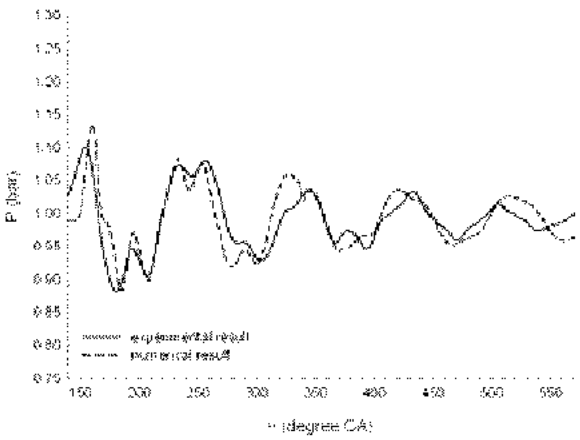

Fig. 6 The comparition of experimental result and numerical result in case of d = 22mm and N – 1,000mm at P_2

curve of P_1 is directly contacted with cylinder, the pressure curve of P_2 is 320mm separated with cylinder and the pressure curve of P_3 is placed middle point. Experimental test timing is ivo to evo. The pressure curve of P_2 shows exhaust pressure, this is transferred by inner reflection wave and affected by shock wave after θ = 360 °. After the first exhaust pressure peak that follows the blow down phase, a second pressure which is due to pressure wave propagation and reflection phenomena in the exhaust system, reaches the exhaust valve during overlap interval, maintaining pressure levels until evc.

Figure 5 shows the numerical results in the case of standard type. The pressure curves of P_1 and P_2 shows the transferred exhaust pressure and these shows higher values than numerical results, this is why the heat transfer and the friction are not considered in this condition.

Figure 6 shows the comparison between experimental and numerical results in the case of l = 1,240mm at P_2. The calculation data are quite close to the experimental data, the numerical calculation seems to slightly overestimate over the N = 1,000rpm, the difference between the computed and experimental data are quite modest.

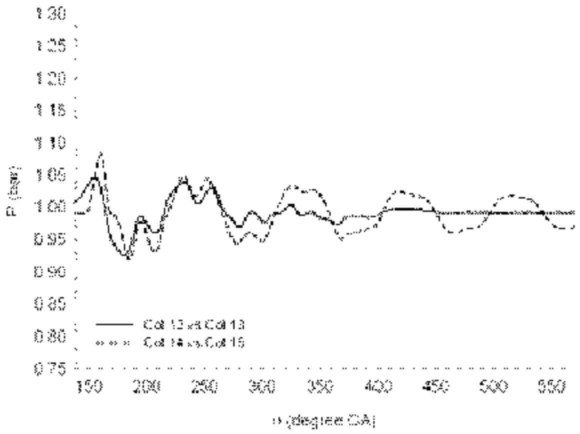

Fig. 7 The comparition of experimental result and numerical result in case of d = **28mm** **and** N – 1,000rpm at P_2

Figure 7 shows the comparison between experimental and numerical results in the case of d = 28mm at P_2. The calculation data are quite close to the experimental data, the exhaust pressure propagation and reflection phenomena in the exhaust system, and the numerical calculation seems to be a slightly overestimation.

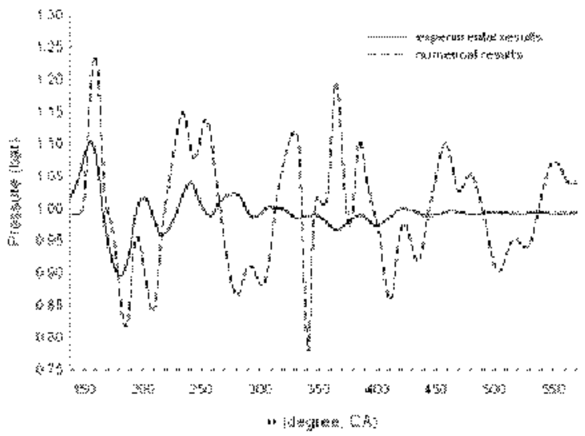

Fig. 8 The comparition of experimental result and numerical result in case of d = **16mm** **and** N – 1,000rpm at P_2

Figure 8 shows the comparison between experimental and numerical results in the case of d = 28mm at P_2. The calculation data are quite different to the experimental data. The reason of this difference is the exhaust pressure propagation, reflection phenomena and resonant are not consider in the exhaust system, and the numerical calculation seems to be a slightly overestimation.

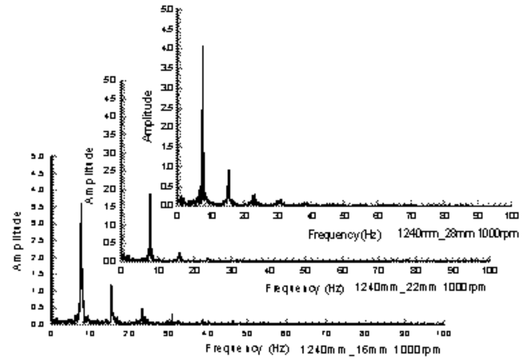

Fig. 9 Experimental results of Fast Fourier Transform for the sound pressure level at d = **16mm, 22mm and** 28mm

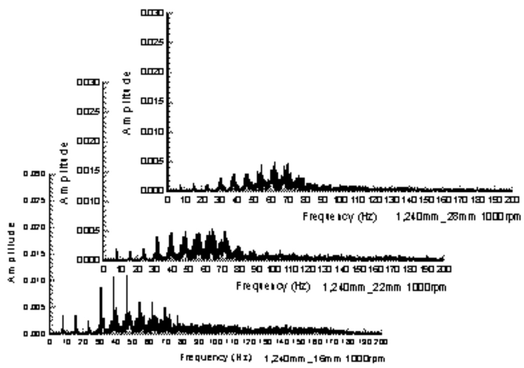

Fig. 10 Experimental results of Fast Fourier Transform for the exhaust pressure level at d = **16mm, 22mm and** 28mm

Figure 9 shows the experimental results of Fast Fourier Transform for sound pressure level at d = 16mm, 22mm and 28mm. The first frequency of Fast Fourier Transform at N = 1,000rpm is 8Hz. The case of d = 22mm has a small amplitude than the case of d = 16mm and 28mm.

Figure 10 shows the experimental results of Fast Fourier Transform for exhaust pressure at d 16mm, 22mm and 28mm. The main frequency of Fast Fourier Transform at N 1,000rpm is 40Hz to 80Hz.

5. CONCLUSIONS

The one dimensional fluid dynamic code has been employed to exhaust pressure, and the predicted data from numerical analysis have been compared with experimental results. Numerical analysis techniques were applied not only to obtain a better understanding of the unsteady flow phenomena that occur during the gas exchange process, but also for the development of a variable geometry exhaust system. In this research, the pressure prediction of exhaust pipe with single cylinder 4-cycle engine is carried out and the main results are as followings.

1) The calculation data are quite close to the experimental data, the numerical calculation seems to slightly overestimate over the various exhaust pipe diameter, the difference between the computed and experimental data are quite modest.

2) The first frequency of Fast Fourier Transform for sound pressure level in case of d = 16mm 22mm and 28mm at N = 1,000rpm is 8Hz.

3) The case of d = 22mm has a small amplitude than the case of d = 16mm and 28mm.

4) The main frequency of Fast Fourier Transform for exhaust pressure in case of d = 16mm, 22mm and 28mm at N = 1,000rpm is 40Hz to 80Hz.

ACKNOWLEDGEMENT

This work was partially supported by the grants from the Brain Korea 21 project, NURI project and the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government.

REFERENCES

1. M.badami, F. millo and G. Giaffreda, "Excremental and computational analysis of a high performance four stroke motorcycle engines equipped with a variable geometry exhaust system", SAE proc., 2002 01 0001, 2002
2. M. mugele, J. Tribulowski, H. Peters and U. Spicher., "Numerical analysis of gas exchange and combustion process in a small two stroke gasoline engine", SAE Jour., Vol. 110, No. 3, pp. 29 35, 2001
3. K. O. Cha, J. S. Lee and H. S. Kim, "A Study on the Characteristics of Pressure Wave Propagation in Automative Exhaust System", KSAE Jour., Vol. 4, No. 4, pp. 18 26, 1996
4. J. E, Oh and K. O, Cha, "Noise reduction of the muffler by optimal design" KSME Int. Jour., 14, 9, pp 947~955. 2000
5. R. S, Benson. "Thermodynamics and Gas Dynamics of Internal Combustion Engine" 1, 246 325, 1982
6. E. D, Winterbone and Pearson, J. R., “Theory of Engine Manifold Design, Professional Engineering”, Publishing Limited, pp18 46, 2000
7. Dermot O. Mackey, John G. Crandall, Glen F. Chatfield and Malcolm C. Ashe, "Optimization of Exhaust Pipe Tuning on a 4 stroke Engine Using Simulation, . SAE proc,. 2002 01 0002, 2002
8. J. Lee, D. Koh, K. Cho, S. Jang and S. Ahn, "A Study on the Gas Flow in Exhaust Manifold of a single Cylinder Diesel Engine", KSPSE. Jour., Vol. 7, No. 1 pp 14 19, 2003
9. H. D. Lee, S. C. Choi, D. K. Koh, C. J. Lee, H. M. Jeong and H. S. Chung, "Characteristics on the Pressure Variations According to the Exhaust Pipe Pressure Shape of 4 Stroke Gasoline Engine", KSPSE. Jour., Vol. 8, No. 1 pp 13 17, 2004
10. S. C. Choi, H. J. Lee, S. H. Kim, D. K. Koh, H. M. Jeong and H. S. Chung, "Pressure Predictions in Exhaust Pipe of a Single Cylinder Gasoline Engine", KSPSE. Jour., Vol. 8, No. 1 pp 24 29, 2004