Shock-absorbing algorithm for front-end loader modified for agricultural purposes with an electro-hydraulic directional valve

Jong-Woo Ha[1], Hak-Jin Kim[1,2*]

(1. *Department of Biosystems Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Korea;*
2. Research Institute for Agriculture and Life Sciences, Seoul National)

Abstract: A front-end loader for agricultural purposes is the most commonly used implement for agri-tractors in Korea. As it is operated to raise, lower and carry various objects in a farming field, it bringsa large amount of stress to a tractor, causing vibrations and often leading to a mechanical breakdown. These high stresses are observed at the starting and ending points of operation, that is, the points at which the highest acceleration and deceleration occur. To reduce the sudden change of the speed, soft-start & end operation were tested with an electrohydraulic directional valve, which has a built-in ramp time spool control function. This valve was controlled by SAE-J1939 associated messages via CAN bus. This shock-absorbing system contains three electronic control unit(ECUs): a loader ECU for receiving and transmitting loader position data, a joystick ECU to convert a lever position that is constantly being changed by an operator into CAN messages, and a valve ECU to regenerate all messages into the J1939 standard to be understood by the electrohydraulic directional valve. By sensing the loader position and speed, the ramp activation point wasdetermined. As expected, applying ramp time control to the front-end loader control system proved to be effective for reducing the shock level, in contrast to that of the conventional control using a hydraulic manual valve.

Keywords: Front-end loader, shock absorbing, electrohydraulic directional valve, ECU

Citation: Ha, J. W., and H. J. Kim. 2015. Shock-absorbing algorithm for front-end loader modified for agricultural purposes with an electro-hydraulic directional valve. Agric Eng Int: CIGR Journal, Special issue 2015: 18th World Congress of CIGR: 310-316.

1 Introduction

As the technology of agricultural attachments has expanded to include electrical control communication via a message based topology, such as J1939 for a tractor and ISO11783 for an attachment, now a large amount of information is able to be transferred on a twisted pair of wires, that is, the CAN bus (Fellmeth, 2003). Since a front-end loader (FEL), which is one of the most frequently used implements with an agricultural tractor, requires various subsystems such as hydraulic, mechanical and electrical parts, complex control algorithms become in high demand (Worley and La Saponara. 2008).Especially, the implementation of delicate and robust control algorithms is essential because FEL working related accidents in many different countries have been reported, and incidents of FEL-related tractor damage have also been reported continuously (Day, 1999).

A front end loader equipped vehicle can not only be prone to excessive pitching during high speed travelling (Rehnberg and Drugge, 2007) but also subject to heavy work, such as round hay bale work, which causes injuries to many operators by accidentally rolling back onto the unprotected tractor operator (Bader, 1997; Friesen and Ekong, 1988; Fellmeth, 2003). However, such accidents could have been prevented if accurate and smart control had been available. These accidents often occurred during a FEL operation at the starting and ending points, at which the fastest acceleration and deceleration occur, resulting in the highest stress being generated.

Received date: 2014-11-24 **Accepted date:** 2015-01-13

***Corresponding author: Hak-Jin Kim,** Seoul National University,Seoul, Korea. Email.kimhj69@snu.ac.kr.

Our goal was to develop a front-end loader (FEL) mounted on an agricultural tractor equipped with a J1939 communicable electro-hydraulic proportional valve (EHPV) to provide smarter control capability than a conventional on & off manual valve control while controlling the EHPV mounted on a tractor defined as Class3 by ISO standard (ISO, 2002a). Toward that goal, in this study, a shock absorbing algorithm based on the measurement of boom cylinder stroke was developed using in-valve pre-programmed ramp time functions. Two electronic control units (ECUs) were simulated by using a software package (CANoeVer. 8.0, Vector Co., Germany) that supports the J1939 network. Due to the limitation of the test space and easier access than an engine driven tractor, a front-end loader simulator was constructed in the laboratory.Applying this software and simulator allowed us to not include ECU hardware and to avoid firmware development time, thereby it allowed us to spend more time on algorithm design (Freimann, 2007). These simulated ECUs communicated with EHPV via the CAN bus and achieved a satisfactory result. Thus, this EHPV equipped FEL was expected to reduce the risk of potential accidents and prolong the lifetime of both the FEL and the tractor.

2 Materials and methods

2.1 Simulator of a front-end loader

Figure 1 shows a simulator of the front-end loader (FEL) that was used for indoor tests. A front-end loader used in a 25hp tractor, an electro-hydraulic proportional valve (EHPV) (Bosch), a DC motor drive, and a hydraulic power unit are the main components of the simulator.

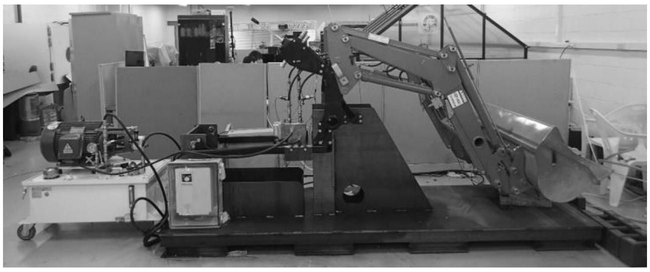


Figure 1 Simulator of a front-end loader control system connected with an EHPV

2.1.1 Front-end loader

Due to the difficulties of performing a field test, the front-end loader (model: ML426 – TAESEONG), which is designed for a 25hp tractor, was mounted onto a jig in the laboratory. To simulate a variable loading weight (0-200 kg) on a bucket, a weight holder was welded in a bucket (Figure 2). By adding up to ten 20kg weights, up to 200 kg of loading capacity was able to be tested.

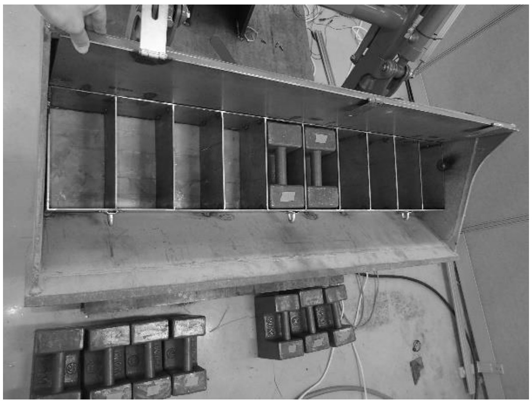
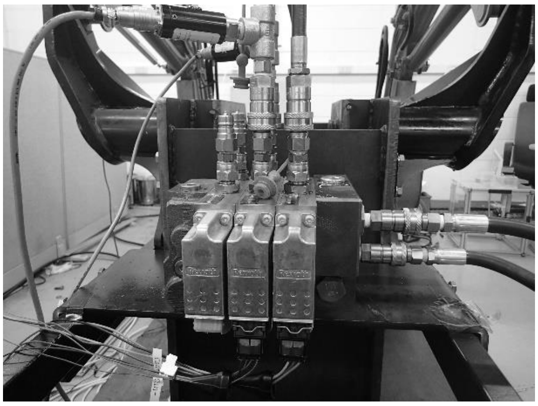


Figure 2 Weight holder in the bucket used in the study

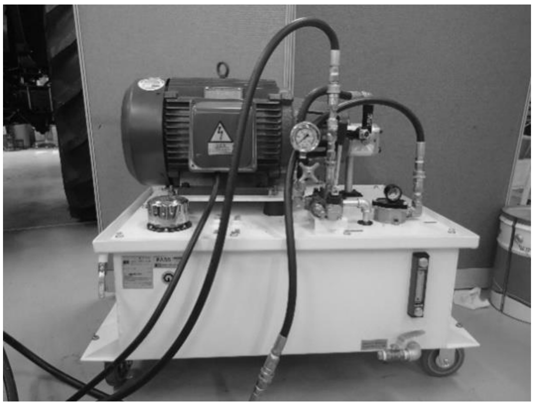
2.1.2 Hydraulic equipment

Figure 3a shows the connections of the EHPV and cylinders for a boom rod. To control a FEL in a manner that prevents sudden changes of oil flow to the cylinders of the FEL, the EHPV (Model: SB23-EHS1, Bosch) was used instead of a conventional manual valve. This EHPV has three sections: the first section for boom cylinder, the second section for bucket cylinder and the third section for spare usage. The nominal oil flow of EHPV is from P to A, with the B port at 100 L/min, but for this laboratory usage, the FEL max oil flow was set as 17.5 L/min to meet a requirement of the FEL (ML426) specification. The oil flow target value can be set as the default by means of a J1939 message. The J1939 message adheres to the general CAN 2.0B conventions, as described in Table 1.

Figure 3b shows the hydraulic supply unit that sends hydraulic oil to the EHPV valve. To support a hydraulic oil flow to the EHPV, a 15kW DC motor with a gear pump, which outputs 24.5L/min, was used to support the hydraulic oil flow. Because the FEL simulator for this study requires 17.5L/min, a DC motor inverter was applied to lower the speed of the motor until it supplies 17.5L/min.



(a)



(b)

Figure 3 EHPV valve and hydraulic oil supplier with a pressure sensor

(a)EHPV valve (b) hydraulic oil supplier with a pressure sensor

Table 1 Loader ECU messages and signals

Msg (ID)	Signal	Start bit	Length	Byte order	Type	Initial value
Loader_ECU_sensor _value0 (0x15x)	Loader_ECU_valve0A_pressure	0	32	Intel	Float	0
	Loader_ECU_valve0B_pressure	32	32	Intel	Float	0
Loader_ECU_sensor _value1 (0x16x)	Loader_ECU_hydro_main_supply	0	32	Intel	Float	0
Loader_ECU_sensor _value2 (0x17x)	Loader_ECU_horizontal_body	0	32	Intel	Float	0
	Loader_ECU_horizontal_boom	32	32	Intel	Float	0
Loader_ECU_sensor _value3 (0x18x)	Loader_ECU_poten_meter_boom	0	32	Intel	Float	0
	Loader_ECU_poten_meter_bucket	32	32	Intel	Float	0

2.1.3 CAN signal generator for a loader control

Figure 4 shows the virtual ECUs, the CAN adapter and the data logging equipment. To control an EHPV, virtual ECUs were designed in a PC environment using the ECU development tool (CANoe). The messages of the ECUs were transmitted via a CAN adapter (VN1630, Vector Co., Germany). To read the sensor signals coming from a potentiometer attached onto the cylinders of the boom and bucket of the FEL, the data logging equipment was connected to ani-7 laptop computer.

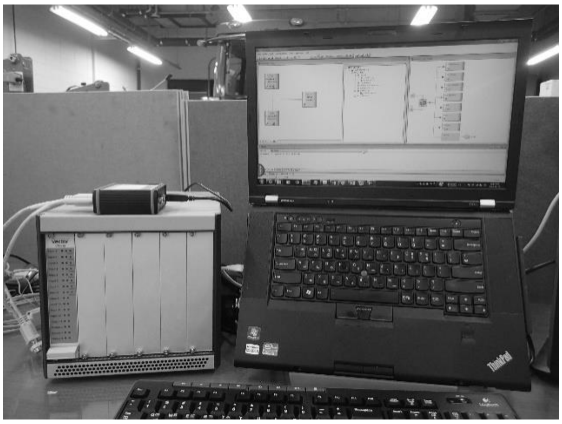
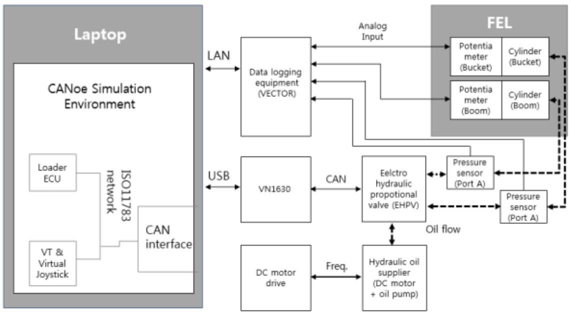


Figure 4 CAN message generator system

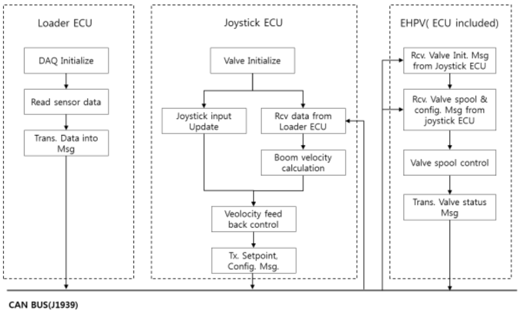
2.2 Topology of ECUs and components of FEL control system

2.2.1 Network topology

To control the FEL, two ECUs were designed in a virtual environment: joystick ECU for a data analysis using an algorithm that sends TX messages to the EHPV and loader ECU that reads the sensor signals of the position of the FEL (Figure 9a). When loader ECU receives sensor signals, loader ECU converts into a message and send them to a CAN bus for an EHPV to decide set points. (ISO, 2002b). A valve ECU is integrated into an EHPV, which receives and send messages in accordance with the J1939 standard. For this loader control system, three ECUs were involved in the communication. All of the network buses used the J1939 protocol to share the network bus with an ECU of the EHPV. Figure9b shows the processes of each ECU.



(a)



(b)

Figure 9 Simulated ECU topology for the FEL loader controland flow chart of the ECUs

(a) Simulated ECU topology for the FEL loader control

(b) Flow chart of the ECUs

2.2.2 FEL control message

For the FEL control, the J1939 messages of the loader ECU and the joystick ECU were assigned to a database, as described Tables 1 and 2, respectively. Eight signals, i.e., pressure of valve A, pressure of valve B, main supply pressure, boom potentiometer, bucket potentiometer, body angle and bucket angle, were generated to transmit digitally converted signals from the sensors attached on FEL. The message data field was limited to eight bytes. As a result, these eight signals were transmitted in four messages. The joystick ECU performs EHPV control, generating the required signals and the messages defined by the EHPV manual (Rexroth, 2012). The EHPV ECU receives four messages: set point, configuration, parameter assignment and flash; the EHPV ECU transmits three messages: status, parameter assignment, and flash. Out of seven messages, two messages of the setpoint, which sets the spool operation, and the configuration, which sets a ramp time, are generated in a joystick ECU. A status message of EHPV shows the valve status, such as the error, valve temperature, oil flow, and maximum oil flow. The parameter assignment message is assigned a valve number by transmitting to the EHPV and then the EHPV transmitting back to the CAN bus if a new assigned valve number is saved. When a valve number is assigned, only one valve should be connected to the CAN bus; otherwise, more than one EHPV can have the same valve number.

Table 2 Joystick ECU messages and signals

Msg (ID)	Signal	Start bit	Length	Byte order	Type	Initial value
V0_config_message_from_VT (0x18FF60FEx)	V0_config_system_information	0	8	Intel	Signed	0
	V0_config_characteristic_form	8	8	Intel	Signed	0
	V0_config_gradient_raise	16	8	Intel	Signed	0
	V0_config_gradient_lower	24	8	Intel	Signed	0
	V0_config_ramp_activated_raise	32	8	Intel	Signed	0
	V0_config_ramp_deactivated_raise	40	8	Intel	Signed	0
	V0_config_ramp_activated_lower	48	8	Intel	Signed	0
	V0_config_ramp_deactivated_lower	56	8	Intel	Signed	0
V0_setpoint_message_from_VT (0x18FF50FEx)	V0_set_system_information	0	8	Intel	Signed	0
	V0_set_diagnosis	8	8	Intel	Signed	0
	V0_set_operation_mode	16	8	Intel	Signed	0
	V0_set_oil_flow_setpoint	24	8	Intel	Signed	0
	V0_set_external_oil_temperature	32	8	Intel	Signed	113
	V0_set_ramp_rounding	40	8	Intel	Signed	0

2.3 Shock absorbing algorithm

EHPV has its own ramp time function that supports a ramp time from 0.2 - 4.3 s. To find when a ramp time must activate, the reference line, which was determined from a damping parameter, was defined in advance (Figure 10). Next, when the measured boom cylinder rod velocity reached at a reference velocity, as shown in Figure 10, the ramp function was activated. On one hand, as the damping parameter value rises, the ramp time becomes shorter, thereby generating more shock to the front-end loader. On the other hand, a longer ramp time results in a slow response. To balance these counteracting effects, the proper damping parameter value must be selected. In this experiment, the damping parameter was set to 500 after observing the movements for several damping parameter values. A maximum 350mm stroke of the cylinders was used for a boom rod. Equation 2 is used to determine the ramp time, which inversely depends on the damping parameter. Equation 1 can be used to determine the ramp starting point. In the experiment, the real cylinder rod velocity could not follow the reference line exactly due to a delay caused by a moving average of the cylinder rod velocity and also the typical embedded time delay.

$$R = \frac{P-D}{\frac{-D}{C}} \quad (1)$$

Where, R is ramp starting point;

P is piston rod velocity;

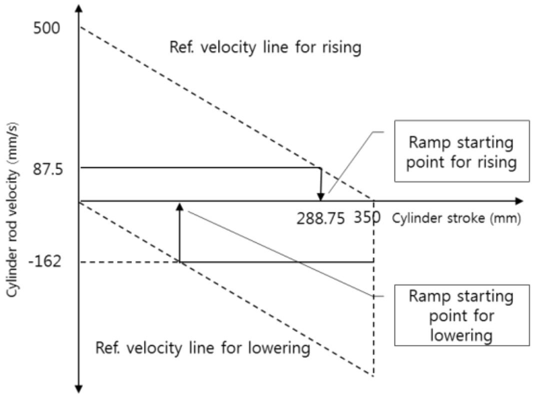
D is damping parameter;

C is cylinder stroke.

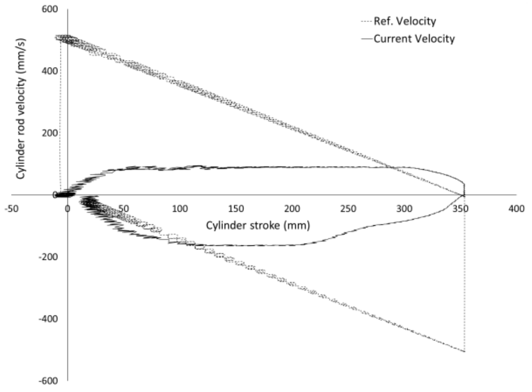
$$R = \frac{F}{0.5\,D} \qquad (2)$$

Where, T is ramp time;

F is cylinder full stroke.



(a)



(b)

Figure 10 Ideal ramp starting point and experimented ramp starting point

(a)Ideal ramp starting point (b)Experimented ramp starting point

3 Results and discussion

Comparing the conventional performance using a manual valve and an EHPV equipped FEL system, Figure 10 shows that the EHPV applied FEL system exhibited superior performance at both the starting and ending points of loader movements while delaying the time to reach an end point compared to that of the case of not using ramp time integration. Port A was connected to a pressure sensor to measure the pressure applied onto a hose that is connected to the boom cylinder; the oil in this hose is pressurized when a piston rod moves forth to lift the boom of the FEL to the top position. Port B is connected to other direction of the hose. The pressure difference of port B between controls with a ramp time and without a ramp time did not exhibit much difference because the weight of the FEL helped it to move to a descending direction, resulting in no high pressure in the hose. The pressure of port A is high when the FEL starts from the lowest point and when it reaches the highest point. Table 3 describes the pressures (MPa) at the points of starting and ending with 0 kg, 100 kg, and 200 kg loaded in a bucket along with the times to reach to the highest position from the lowest position.

Table 3 Pressure on port A and the required time of the FEL movement

Load weight,kg	Pressure at the lowest position, MPa		Pressure at the highest position, MPa		Working time to reach at top position, s	
	No Ramp	Ramp	No Ramp	Ramp	No Ramp	Ramp
0	13.57	5.23	16.42	14.82	3.58	4.91
100	14.80	6.04	17.72	15.42	3.77	5.13
200	15.35	10.33	20.67	15.72	3.77	4.69

Figure 11a shows the differences of the pressure of port A with 0 kg, 100 kg and 200 kg loaded in a bucket without a ramp function, and Figure 11b shows the pressures when a ramp function was used. Comparing those two figures, a pressure reduction of port A at the highest point was observed. From Figure11, with the ramp applied, Figure 11b exhibits a high peak pressure, as shown in Figure 11a, at the highest point.

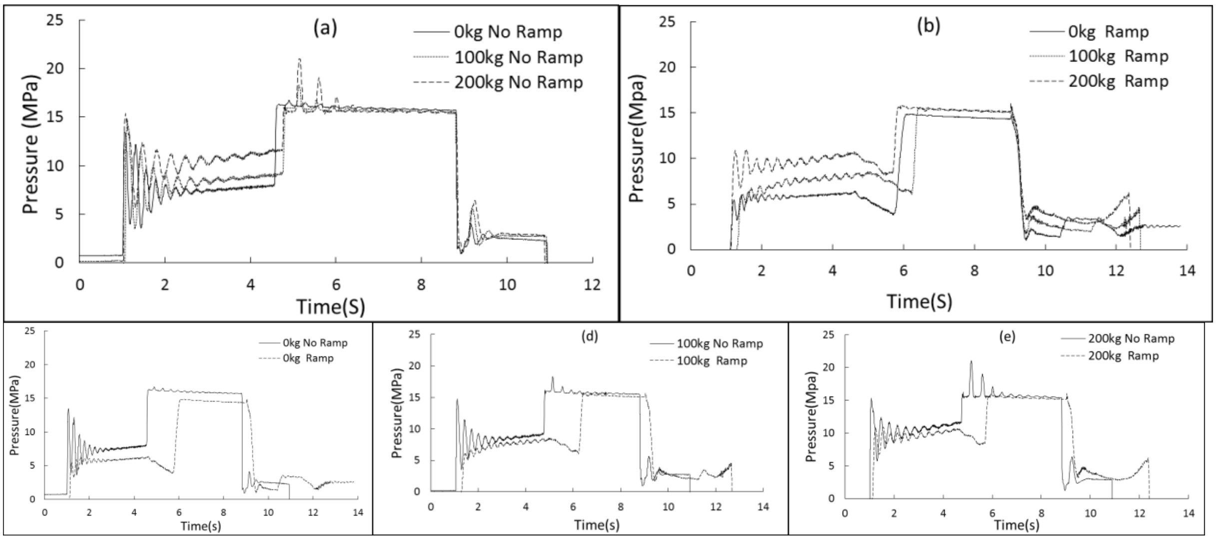


Figure 11 Hydraulic oil pressure on port A with 0 kg, 100 kg, and 200 kg loaded on a bucket for both manual and ramp time applied control

4 Conclusion

This study confirmed the effectiveness of EHPV based front-end loader control to provide shock reduction. The EHPV based control achieved a satisfactory result regarding the movements of a boom rod, especially at the starting and ending points, demonstrating an improved performance compared to an on-off hydraulic valve. Although only a small-sized loader was tested with this EHPV system, a large-sized loader will be expected to be applicable simply by tuning the parameter of the damping coefficient. Because a pre-programmed ramp function was used, control of the ramp time was easy to handle; however, the system was not allowed to control ramp activation. To control a valve spool during ramping, each discrete ramp control point must be sent repeatedly at a constant rate by applying a closed-loop feedback mechanism, such as PID control.

Further studies are required to reduce the time delay of the ramp activation. In addition, tests must be performed after a simulated front-end loader is attached to a real tractor on a farming field.

References

Bader, M. J., L. R. Walton, and L. G. Wells. 1997. Dynamic stability of two tractor front-end loader systems. *Transactions of the ASAE,* 40(4): 865-869

Day, L. M. 1999. Farm work related fatalities among adults in Victoria, Australia: the human cost of agriculture. *Accident Analysis & Prevention*, 31(1):153-159.

Fellmeth, P. 2003. CAN-based tractor-agricultural implement communication ISO 11783. *CAN Newsletter* 9.

Freimann, R. 2007. A basic approach to implement guided tractor control.

Friesen, R. W., and C. Ekong. 1988. Spinal injuries due to front-end bale loaders.*CMAJ: Canadian Medical Association Journal*, 138(1):43.

ISO. 2002 ISO 11783: Tractors and machinery for agriculture and forestry - Serial control and communications data network, Part 7 Implement messages application layer. Geneva, Switzerland: ISO, *International Organization for Standardization.*

ISO. 2002 ISO 11783: Tractors and machinery for agriculture and forestry - Serial control and communications data network, Part 9 Tractor ECU. Geneva, Switzerland: ISO, *International Organization for Standardization.*

Rehnberg, A., and L. Drugge. 2007. Pitch Comfort Optimisation of a Front End Loader Using a Hydropneumatic Suspension: SAE Technical Paper.

Rexroth Bosch Group 2012. Technical customer documentation (TKU) - Electronics section - SB23-EHS1RD with standard software R917006776.

Worley, M. D. and V. La Saponara. 2008. A simplified dynamic model for front-end loader design. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science Vol.* 222: 2231