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지게차 변속제어밸브의 모델링 및 성능 검증
Modeling and Performance Investigation of Forklift Transmission Control Valve System

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Abstract: In forklifts, the machine performance is largely depended on the transmission performance. The aim of this paper is to develop a complete model of transmission control valve (TMV) system of a typical forklift using AMESim simulation tool. By using the developed TMV model, it becomes easy to investigate the system concept, working principle, and performance. In addition, an optimization on the TMV structure can be achieved by using this model with tunable parameters. Simulations have been carried out in a comparison with the actual experiments to verify the model.

1. Introduction

This paper proposes a modeling method for a typical valve control system of the engine forklift transmission from MS Precision[1,2] using the Hydraulic Component Design (HCD) library in the AMESim simulation tool[3-5]. The transmission control valve controls the transmission of forklift trucks. It keeps the set pressure and operates torque converter and clutch. When the clutch is engaged, torque is transferred from torque converter to each actuator, which makes it possible for the vehicle to move forward and backward. AMESim (Advanced Modeling Environment for performing Simulations) is organized in component libraries. The components, represented by symbolically technologically suggested icons, can be interconnected exactly like the system under study.

Therefore, the HCD library is used to modeling all components of the TMV control circuit in order to build the overall circuit in which the setting parameters are similar with the given parameters from the real control valve block. Simulations and real tests have been done to evaluate the design valve control model.

2. Transmission Control Valve System Review

In this study, a typical TMV system from MS Precision Corporation was used for further investigations. The TMV configuration is represented in Fig. 1. From this figure, it can be seen that the TMV system includes mainly four valves: main pressure relief valve, inching valve, modulating valve, and forward/reverse valve. Working functions of these control valves are listed as:

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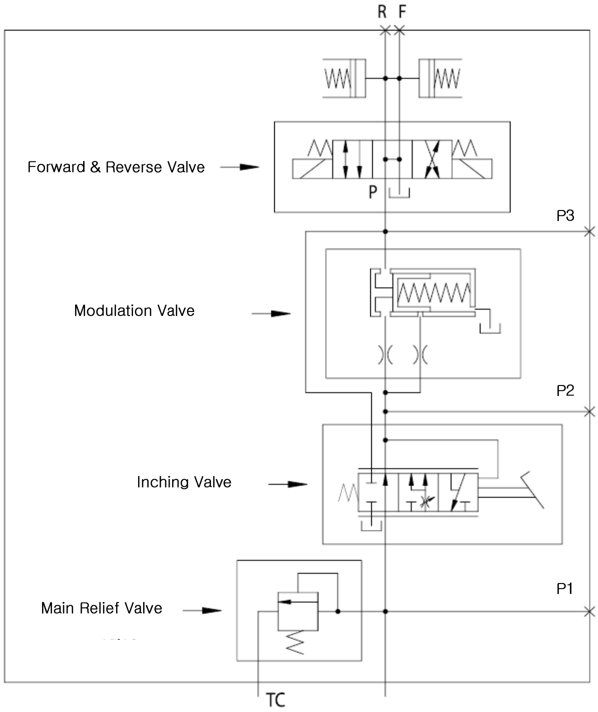


Fig. 1 TMV circuit of the forklift

+ Main pressure relief valve: is to keep the system pressure stably (P1) during the operation. Consequently, this valve prevents quick pressure fluctuations. When it opens, it supplies oil to the torque converter (TC).

+ Inching valve: makes the clutch contact smoother by regulating the oil pressure into the clutch.

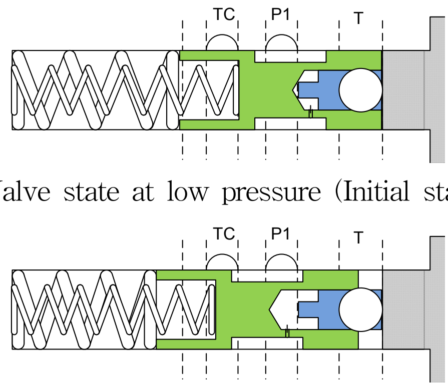
+ Modulating valve: makes the clutch operation smoother by increasing the pressure rising time from the clutch contact.

+ Forward/reverse valve: determines the direction of vehicle by controlling the oil flow after receiving the electric signals (DC12V, DC24V).

3. TMV Model Design

3.1 Main pressure relief valve

The configuration of this valve is depicted in Fig. 2. In this valve structure, there are two compression springs which are used to create the setting relief pressure. At low pressure condition, the valve spool is kept at initial position by the springs to allow the pressurized flow go through port P1. When the working pressure is over than



a) Valve state at low pressure (Initial state)

b) Valve state at cracking pressure

Fig. 2 Main pressure relief valve configuration

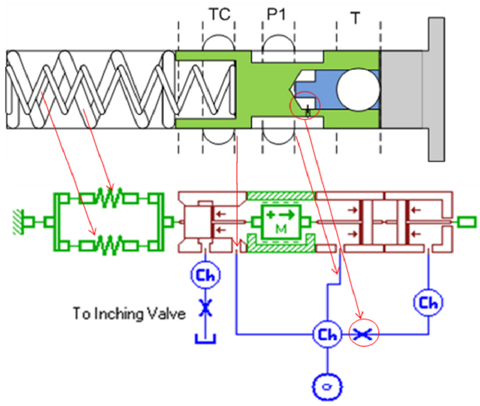
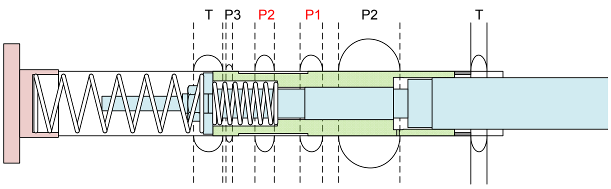


Fig. 3 Model of the main relief valve

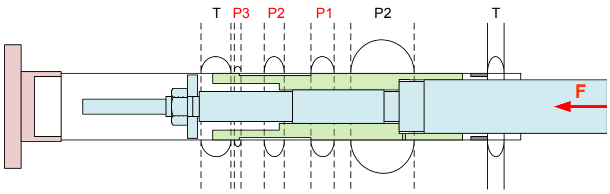
the setting pressure, the spool is moved left to make a balance with the springs. Port P1 is then connected to the torque converter TC to reduce the main pressure. As a result, the main pressure is kept stably. Based on the valve structure and working functions, a representative AMESim model of this valve is built from the HCD components as in Fig. 3.

3.2 Inching valve

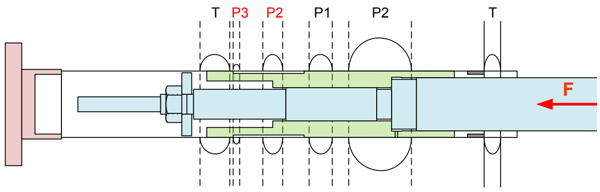
In order to make the clutch contact smoother by regulating the oil pressure into the clutch, the inching valve is suggested to use. As the configuration displayed in Fig. 4, this valve contains a manually acting spool, a sliding envelope and two compression springs. In the initial state, the small size spring is compressed in the inverse direction with the large size spring. During a manual press from pedal mechanism, the small spring is slowly released while the large



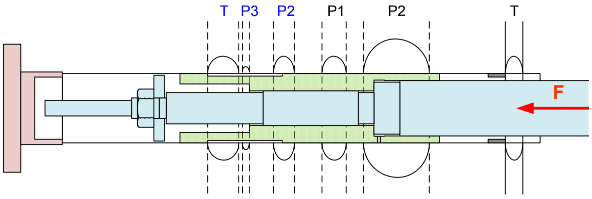
a) Valve at state 01 (Initial state)



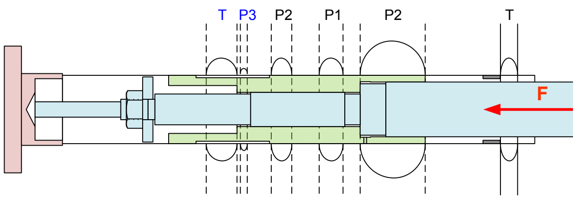
b) Valve at state 02



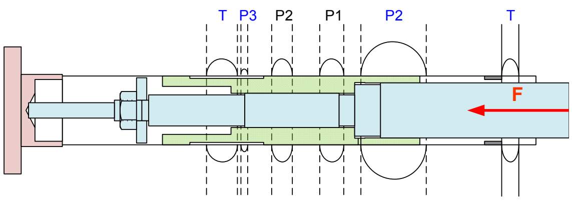
c) Valve at state 03



d) Valve at state 04



e) Valve at state 05



f) Valve at state 06

Fig. 4 Inching valve configuration

spring is more compressed and subsequently, it adjusts the system pressures P2 and P3. Disregarding the motion of the sliding envelope, the operation of the manually acting spool corresponding to the port connections can be divided into six stages as shown in Fig. 4. Based on the valve structure and working functions, a representative AMESim model of this valve is built from the HCD library as in Fig. 5.

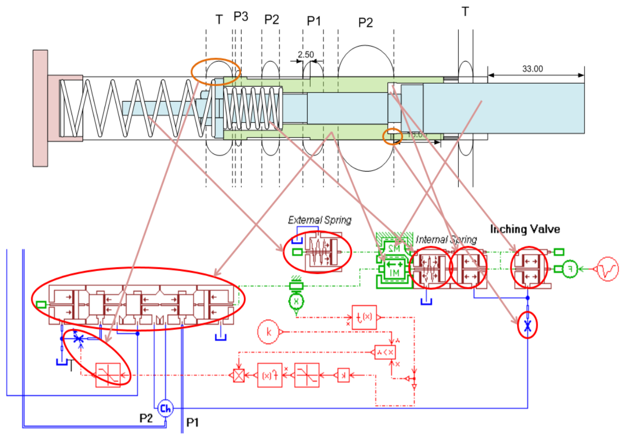
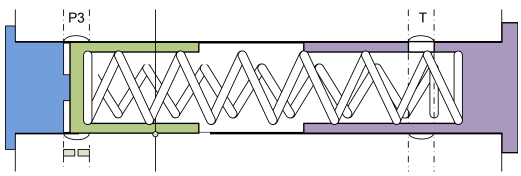


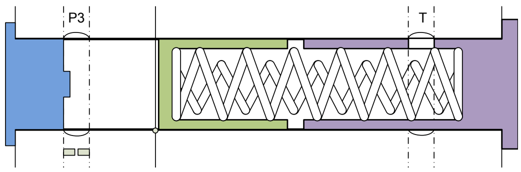
Fig. 5 Model of the inching valve

3.3 Modulating valve

In order to make the clutch operation smoother by increasing the pressure rising time from the clutch contact, the modulating valve is employed. Here, this valve is a combination of two compression springs and a sliding envelope as shown in Fig. 6. At the initial state, the inner spring is in free-state while the outer spring is slightly compressed. During the working process with pressure increase, the sliding envelope is moved right to make a balance with the springs. These two springs are then compressed in the sequence to make a smooth operating pressure. Based on the valve structure and working functions, a representative AMESim model of this valve is built from the HCD components as in Fig. 7.



a) Valve state at low pressure (Initial state)



b) Valve state at high pressure

Fig. 6 Modulating valve configuration

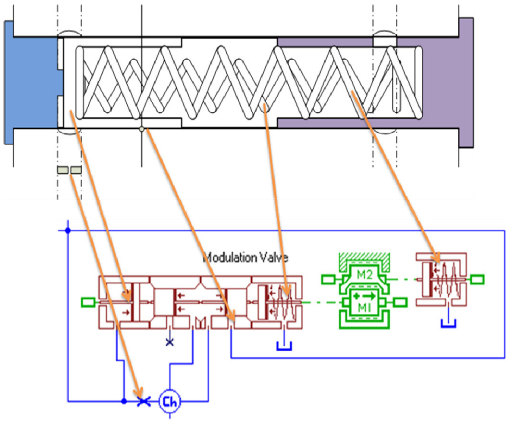


Fig. 7 Model of the modulating valve

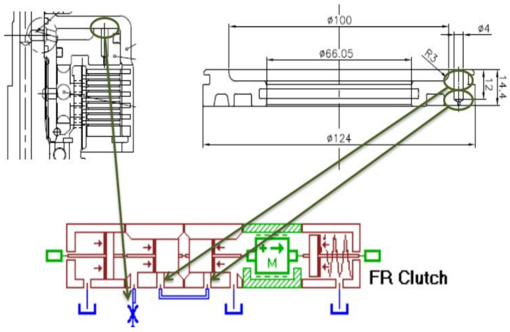


Fig. 8 Model of the engine clutch

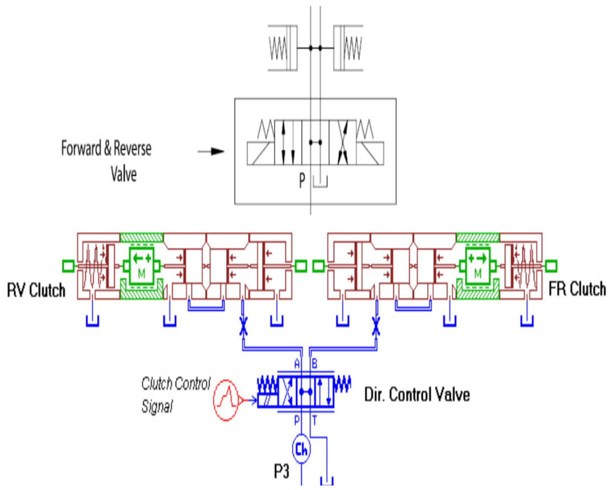


Fig. 9 Model of the forward/reverse valve

3.4 Forward/Reverse valve and engine clutch

The forward/reverse valve and engine clutch are finally investigated. Based on the mechanical design of the clutch and forward/reverse valve, the models for these components are built as shown in Fig. 8 and Fig. 9, respectively.

Finally, the full TMV circuit is constructed as depicted in Fig. 10.

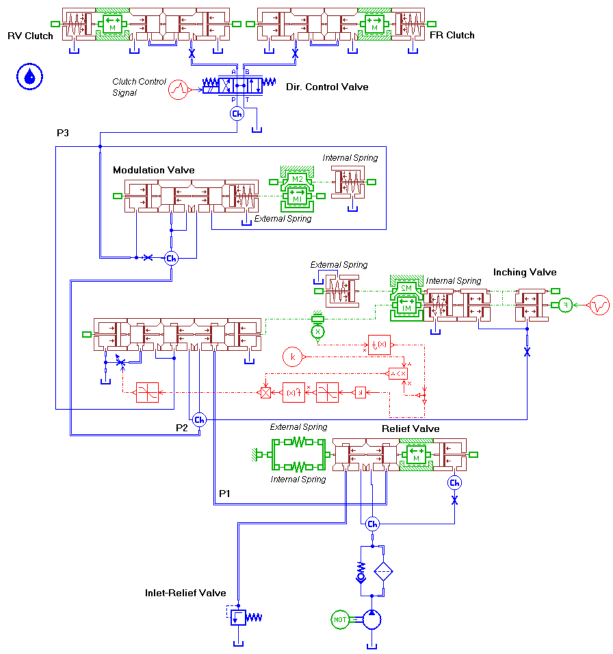


Fig. 10 Model of the TMV circuit

4. Model Verification

4.1 Experimental apparatus

An experimental apparatus was setup with the TMV system as shown in Fig. 11 to investigate the actual performance. The system was tested under the operation of the pump with 16.6cc/rev of displacement and 800rpm of rotational speed.

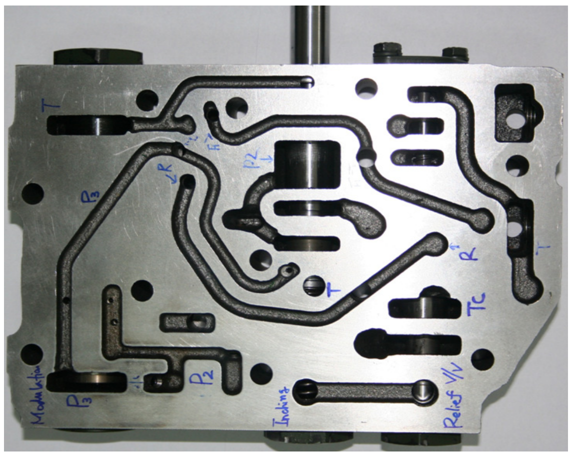


Fig. 11 TMV system apparatus

An experiment on the TMV system with forward clutch control signal was done during a press on the inching valve through the pedal mechanism. In order to evaluate the system as well as the TMV model, stroke of the inching valve was measured by a linear variable differential transformer (LVDT) displacement sensor while the system pressures were monitored by pressure sensors. Subsequently, the system pressure performance was obtained as analyzed in Fig. 12. Next, simulations with the designed TMV model were carried out to validate this model.

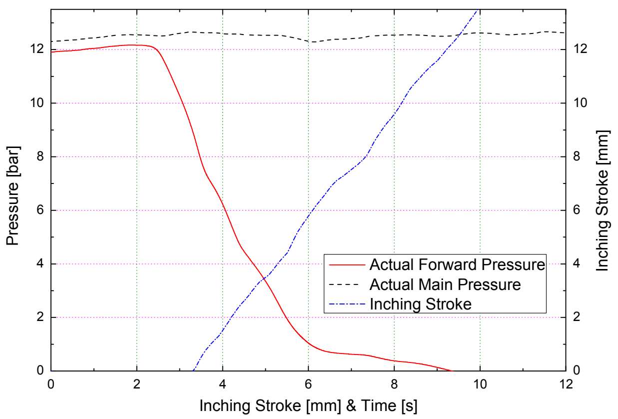


Fig. 12 System performance with respect to inching valve operation

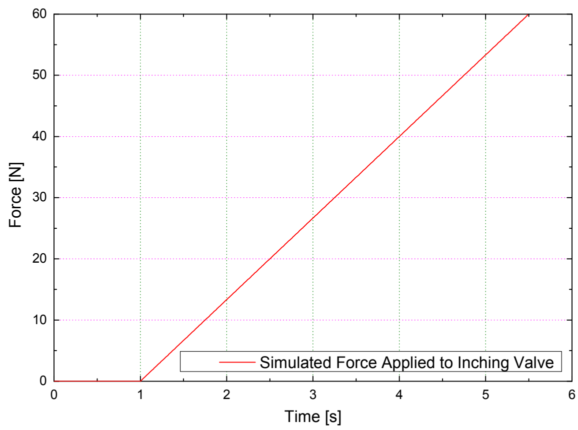


Fig. 13 Force signal applied on inching valve

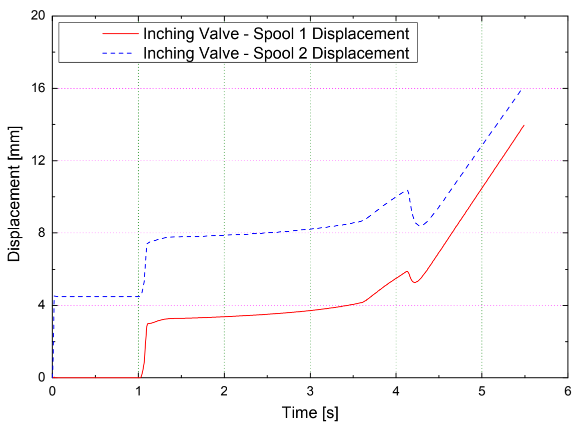


Fig. 14 Simulated inching valve performance

4.2 Simulations and analysis

Simulations with the TMV model built in Section 3 were carried out in the same conditions of the experiment.

Firstly, the model was tested with the press action on the inching valve. To make the similar action as the actual inching performance, a force signal was generated on the main spool of this valve model (see Fig. 13). The simulation results were obtained as shown in Fig. 14 and Fig. 15.

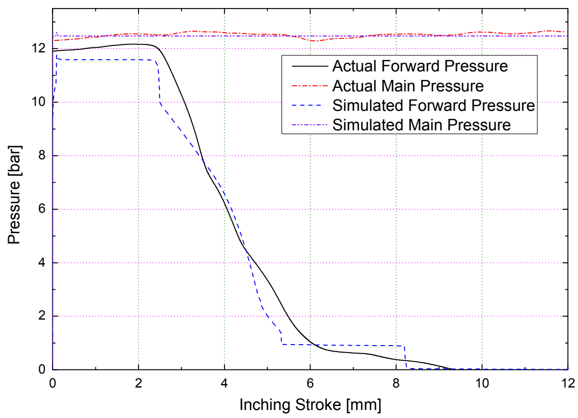


Fig. 15 Comparison between simulation and experimental results

Fig. 14 displays the inching valve performance corresponding to the applied force signal in Fig. 13. Here, the spool 1 displacement (red-solid line) represents for the main spool motion while the spool 2 displacement represents for the sliding envelop of this valve. It can be seen that the motion of both components were depended not only on the applied force but also the system pressure. As a result, a smooth operation can be obtained by adjusting the applied force and valve parameters, such as the springs, etc. The simulated system pressure performance was analyzed in a comparison with the actual performance as plotted in Fig. 15. The result shows that the modeling result was quite similar as the actual system response, except some critical changing points during the inching press action.

The reason is that the simulated inching stroke was not fit with the actual stroke generated by the operator due to using open-loop test in the simulation.

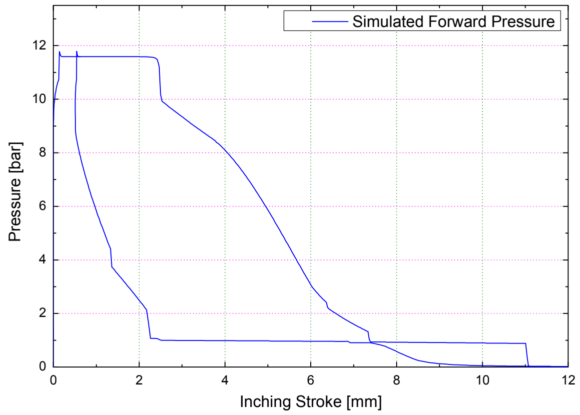


Fig. 16 Simulated system responses due to press and release actions on the inching valve vs. Inching valve stroke

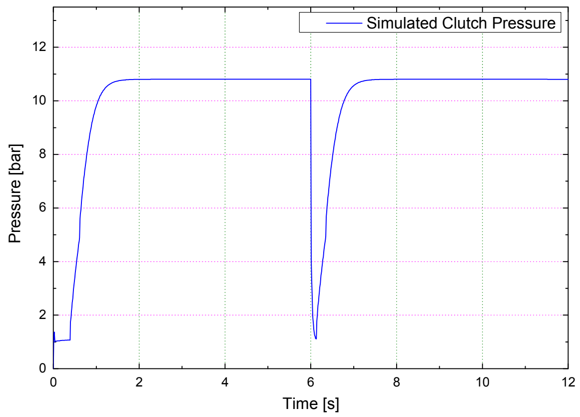


Fig. 17 Simulated system responses due to press and release actions on the inching valve vs. Time

Next, in order to investigate clearly about the TMV performance, a simulation for a combined action, press and then release, applied to the inching valve was performed. The simulation results were then shown in figures 16 and 17. From these results, it can be seen that the clutch pressure performance changed with similar forms for both the press and release actions of the inching valve. It could make a suitable sense for the operator when operates this machine.

5. Conclusions

Transmission control valve system in forklifts has been investigated in this paper. A modeling method for this valve control system has been proposed by using the Hydraulic Component Design library in the AMESim simulation software. A test rig was setup to obtain the actual performance for further investigations with the developed model. The simulation results compared with the real test data proved the adaptability of the proposed model. It can be seen that the model have strong ability to represent for the real system with similar working characteristics. This model is then useful to investigate the TMV system with different design parameters.

As future work, a mathematic model of the TMV is developed in order to combine with the modeling results of TMV AMESim model to construct a graphic user interface tool in MATLAB. Once this tool is completed, it becomes an effective method to design and optimize the forklift transmission performance.

References

1) MS Precision forklift transmission – http://www.powertrainglobal.com/eng/product/product01_01.html
2) Y. M. Jeong, K. Lim, S. Y. Yang, “A Study on Applying the Direct Control Method for Small Forklift Transmission System”, Transactions of The Korea Fluid Power Systems Society, Vol. 10, No. 4, pp.34-40, 2013
3) AMESim user manual, IMAGINE S.A., 2004
4) Y. H. Yoon, “Introduction to AMESim Software”, Transactions of The Korea Fluid Power Systems Society, Vol. 2, No. 1, pp.3-9, 2005
5) K. W. Lee and K. W. Song, “Research Trends and Development Applications on Mobile Hydraulic using AMESim”, Transactions of The Korea Fluid Power Systems Society, Vol. 9, No. 1, pp.52-55, 2012