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Impact Wrench의 체계적인 설계를 위한 동역학 해석 방법에 대한 고찰

On the study of methodology of dynamic analysis for systematic designing Impact Wrench

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Key Words : 동역학 해석(Dynamic Analysis), 체계적인 설계(Systematic Design), Impact Wrench

ABSTRACT

Impact wrench has a sophisticated structure to implement various pre-designed mechanisms with specific functions. In the structure of impact wrench, the gear box has an important role to generate impacting force of anvil from actuating torque. Since, it requires to design systematically the gear box for accurate mechanism of operation and transferring motions. In this paper, a methodology of dynamic analysis, which is useful to design mechanical system, is proposed and applied to impact wrench, sequentially. At first, the way to perform dynamic analysis for design, which is progressed from component to assembled system, is introduced. Secondly, the proposed methodology is applied to designing impact wrench. Eventually, the results of parameter study with proposed methodology are applied to actual design for design optimization. And optimized-design is evaluated in the view of accurate operation and structural stability.

기 호 설 명

ζ_g : Gear Ratio

N_{impact} : The number of Impacting

w_s : Angular velocity of sun-gear

w_p : Angular velocity of spindle

r_r : Radius of ring-gear

r_s : Radius of sun-gear

τ_{im} : Impacting Torque

$\overrightarrow{F_{im}}$: Impacting(Contact) Force

$\overrightarrow{r_{cp}}$: Vector of contact position

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1. Introduction

Recently, mechanical system has become sophisticated and complex due to physical and geometrical nonlinearities from rapidly developed technologies in industrial fields(1). Generally, the mechanical system consists of multi-bodies, which are rigid or flexible bodies, and various kinds of constraints such as joints. Therefore, it requires to design, step-by-step, mechanical system for operating as intended mechanism and to improve structural robustness.

In general, rigid-body dynamics is under an assumption that all component has no elastic deformation. One of advantageous points of rigid-body dynamics is to be capable of demonstrating mechanism of system and estimating reaction force about specific behavior with low computational cost[2]. It is also used to design desired prototyping and other wide applications of testing including control. And various methodologies for multibody analysis are suggested like dividing subsystem and recursively analyzing[3].

Flexible-body dynamics had been introduced to concern deformable bodies which are impossible to be considered by rigid-body dynamics[4]. The dynamic analysis of flexible-body usually results stress, strain and deformation considering elasticity of bodies. Furthermore, results of flexible-body dynamics can be referred to predict quality of machinery system. Since the dynamic analysis of flexible-body takes much more cost rather than rigid-body analysis, the number of executing the analysis should be minimized.

In this paper, a methodology for effective dynamic analysis is proposed to verify design of multi-body systems and improve structural stability of them, systematically. We discuss the guidelines to utilize rigid-body and flexible-body dynamics, simultaneously or sequentially, in the system engineering approach with parameter study.

As an application, the proposed approach applies to design of Impact Wrench, which is one of power-tool machinery generating vibration[5]. In the impact wrench, a gear box, which is one of compositions, has an important role to transfer rotating motion to tip of tool from motor. The gear box is analyzed by the proposed methodology and the efficiency of the proposed method are proved by evaluating design with parameter studies.

2. Methodology for Dynamic Analysis

In this paper, 4 steps are proposed as a guideline for designing mechanical system. As the first step, modeling geometry of the system including boundary conditions and derivation of dynamic equation are implemented. Secondly, rigid-body analysis and flexible-body analysis in module level

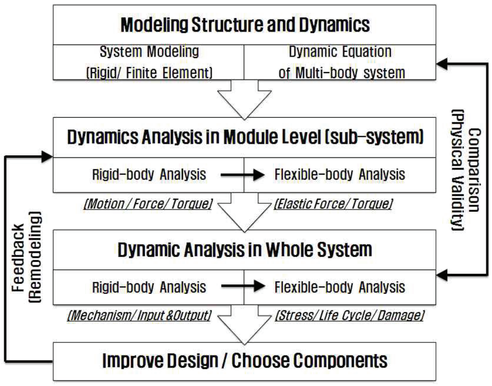

Figure 1. Flow Chart of Methodology

or components are performed respectively. In third step, based on the results of both analysis, operation mechanism and structural stability of assembled system are verified by dynamic analysis. The results of analysis give feedback to improve or complement design of system. The proposed methodology is partially or entirely repeated until design of the system is determined.

2.1 Modeling Structure of System

(1) System modeling

The first guideline of dynamic analysis is to construct system model with or without reasonable simplifications. Factors for system modeling based on geometry can be categorized as body, constraint and contact accounting for operation of the system as shown [Table 1].

Table 1 Category of model for dynamic analysis

Body	Constraint	Contact
Rigid model	Joint/ Primitive/ Coupler	Body-to-Body Contact
Finite Element model		Self Contact

(2) Defining Conditions based on Operation

Well-conditioned input and boundary conditions describing operational environment are significantly important to ensure the comprehensive results of dynamic analysis. Input type is classified as motion level and force level shown as [Table 2].

Boundary conditions should be defined based on operational condition and environment.

Table 2 Input and conditions for dynamic analysis

Input	Boundary Condition
Motion Level (Displacement/ Velocity/ Acceleration)	Based on operational Environment
Force Level (Force/ Torque)	

2.2 Dynamics Analysis in Module Level

(1) Rigid-body Analysis in module level

To implement dynamic analysis of rigid-body in module level, whole model should be disintegrated with respect to meaningful subsystem. The mechanism would be identified, step-by-step, in the law of proximo-distal from input joint. Reaction forces and torques about generated motion are given as results of analysis.

$$\begin{bmatrix} F \\ \tau \end{bmatrix} = solve(x, v, \alpha)$$

(2) Flexible-body Analysis in module level

If there were deformable or fragile parts in the separated module, flexible analysis is implemented by replacing the part from rigid-body to flexible -body. When the flexible analysis is executed, the results of rigid-body analysis, which are reaction force and torque, is capable of referring to lead elastic force, stress and strain.

$$\begin{bmatrix} \sigma \\ \epsilon \end{bmatrix} = solve(F, \tau)$$

2.3 Dynamic Analysis of Whole System

(1) Rigid Analysis of Whole System

The main objective of this step is to confirm operating mechanism of entire system with respect to defined input and boundary conditions. In the rigid-body analysis of assembled system, investigating corelation between design variables and characteristics of mechanism is useful to modify design or compensate the defect.

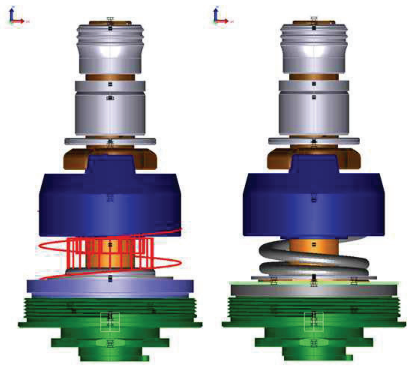

Figure 2. Modeling of gearbox in Impact Wrench: Rigid(left) Flexible(right)

(2) Flexible Analysis of Whole System

Another method to supplement system that is inadequate is to use the results of flexible analysis of assembled system. When the system generates a periodic motion, life cycle or damage at the fragile components can predict by using the results during one cycle of motions. Because flexible analysis requires heavy computational cost, we suggest to construct model by replacing not all bodies but only fragile bodies or to use another analysis software specialized in structural analysis with conditions from rigid-body analysis.

(3) Design Feedback and Parameter Studies

The results of rigid analysis and flexible analysis of whole system is capable of being used to improve performance and robustness of system. Moreover, dynamic characteristics with respect to varying design parameters are obtained to optimize design.

3. Applying to Impact Wrench Machinery

As an example to show effectiveness of the proposed methodology, the proposed approach is applied to design of impact wrench. Geometric modeling and dynamic analysis are respectively conducted by SolidWorks(6) and DAFUL(7) specialized in dynamic analysis of multi-body system.

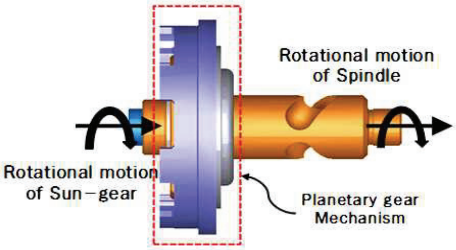

Figure 3. 1st Subsystem of the system

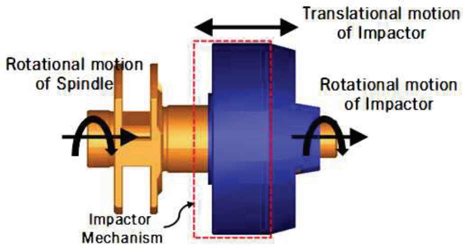

Figure 4. 2nd Subsystem of the system

3.1 System Modeling

(1) Geometric Modeling and Defining Condition

Two kinds of modeling are implemented for demonstrating the proposed methodology. One of them is based on rigid-body and the other consists of both rigid-body and flexible-body as [Figure 2].

we define boundary condition and input profile to perform dynamic analysis. At first, we assume that there is no variation of position and orientation at anvil for analyzing the system under harsh operation condition.

$$\begin{bmatrix} \triangle x \\ \triangle y \\ \triangle z \end{bmatrix}_{anvil} = \begin{bmatrix} \triangle \psi \\ \triangle \theta \\ \triangle \phi \end{bmatrix}_{anvil} = 0$$

And, input profile is defined based on operation specification (N_{impact}) which is 3600 impacting times per a minute. The impacting times can be converted to rotational velocity of sun-gear and continuous profile is generated for acting sun-gear joint as an input.

$$w_{input} = \frac{N_{impact}}{2 \times 60} \times 2\pi \times \zeta_g (rad/\sec)$$

and

$$w_s(t) = \frac{w_{input}}{2} + \frac{w_{input}}{2} sin\left[\pi\left(\frac{t-t_0}{t_f - t_0}\right) - \frac{\pi}{2}\right]$$

3.2 Dynamics Analysis in Module Level

(1) Rigid-body Analysis in module level

The system is separated as two subsystems; one of them is a planetary gear module with spindle and the other is the part assembled spindle and impactor as shown [Figure 3] and [Figure 4].

A ratio between two angular velocities of sun-gear and spindle is determined by specifications of gear module. The ratio of velocity is theocratically calculated as

$$\frac{w_s}{w_p} = \frac{r_s + r_r}{r_s} = \frac{25.50 + 3.50}{3.500} = 8.285$$

Compared with theocratical ratio of velocity, the results of dynamic analysis, which is implemented with respect to varying stiffness of spring, are validated with less than 1% error excluding peaks as [Figure 5].

In the 2nd subsystem, the rotational motion of spindle changes to rotational and translational motions of impactor. More specifically, the rotational motion of spindle leads to the translational motion of impactor when the impactor is impassible to rotate due to the Impactor Locker. After avoiding impactor locker, the impactor rotates again without translation.

Angular and linear velocities of impactor with

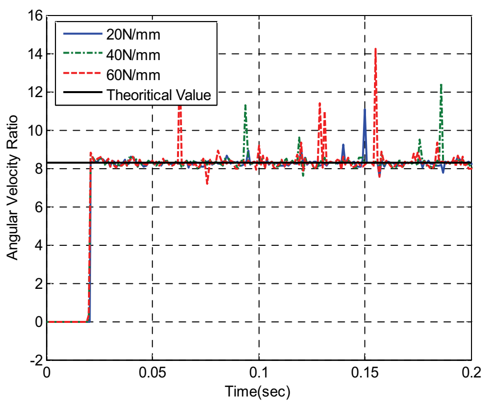

Figure 5. Velocity Ratio of 1st Subsystem

respect to varying spring coefficients are represented in [Figure 6]. The results show that the higher stiffness of spring, the larger amplitude of velocities. What we focused on is that a frequency of impacting is consistent regardless of spring coefficient, which is only depend on the velocity of input velocity.

(2) Flexible-body Analysis in component level

One of important components which consists of impact wrench is spring located between the impactor and the spindle. An elastic force from the spring acts as a reaction force which is applied to impactor. 280N reaction force is estimated under 14mm compression in flexible-body analysis. Based on the results, the coefficient of spring is concluded as 20N/mm.

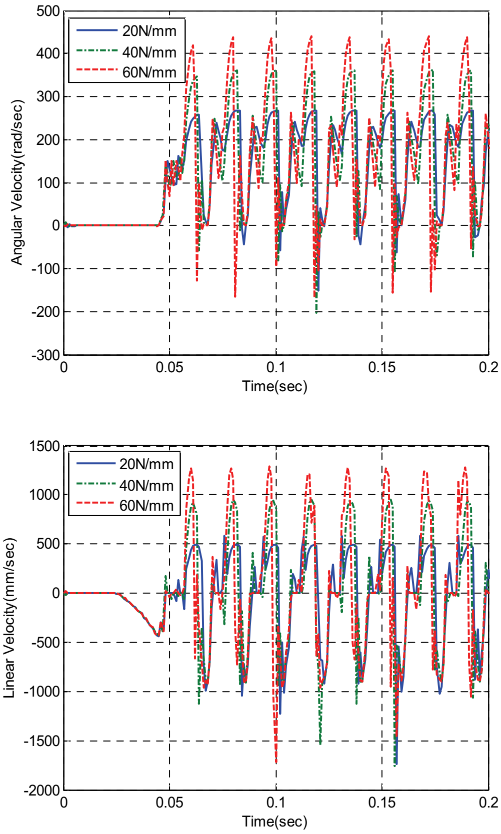

Figure 6. Angular and Linear Velocities of Impactor

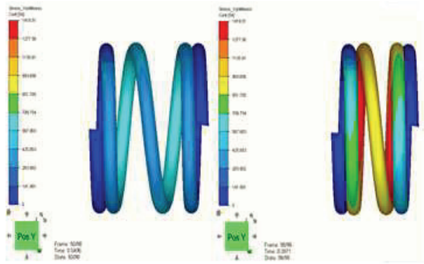

Figure 7. Flexible Analysis of Spring

3.3 Dynamic Analysis of Whole System

(1) Rigid Analysis of whole system

When impactor contacts to impactor locker, contact forces generates torque applying to anvil in an contact instant.

$$\tau_{im} = \sum \overrightarrow{F_{im}} \times \overrightarrow{r_{cp}}.$$

Therefore, the correlation between spring coefficient and contact force should be clarified for optimal design satisfying specifications: impacting torque. Magnitude of contact force has approximately linear correlation with respect to spring coefficient as shown [Figure 8].

(2) Flexible Analysis of whole system

By replacing rigid-bodies of gear module and spring, flexible analysis of assembled system would be demonstrated. What we focus on is to concentrate stress as 147.7Mpa at the notch of ring gear. Repeated concentration of stress should be avoided to prevent fatigue failure during

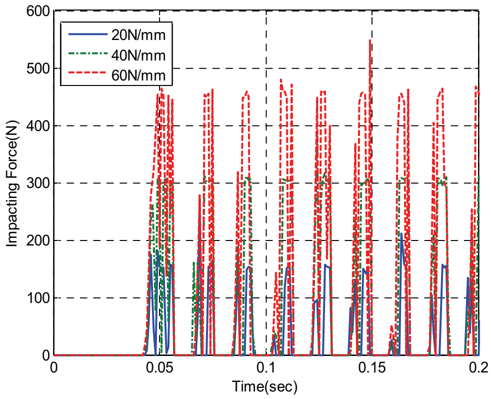

Figure 8. Impacting Force of Impactor

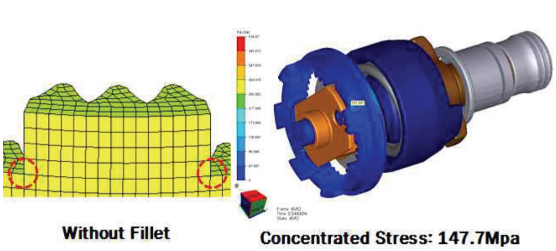

Figure 9. Concentration of stress at the ring gear

operation.

(3) Design Feedback and Evaluation

We discuss that the stress is concentrated on notch of ring gear in previous section. To resolve the problem, design feedback, which is applying fillet to the notch, is suggested. As a result, the stress level at that pont is decreased as 112.7MPa.

Based on the results of dynamic analysis implemented by the proposed guideline, the design is evaluated in views of mechanism, contact force and fatigue aspect. The given specifications requires an impact torque more than 300N with proper operation. The stiffness of spring should be more than 40N/mm. To sum up, the results of evaluation are shown in [Table 3].

Table 3 Evaluating design with respect to spec.

	Evaluation	Complements
Operation Mechanism	Satisfy	non-required
Contact Force (20N/mm)	Low force (more 300N)	Higher stiffness of spring (40N/mm)
Fatigue Aspect	High stress at ring-gear	Applying Fillet

4. Conclusion

In this paper, a methodology of dynamic analysis is proposed to design Impact Wrench, systematically. With rigid-body and flexible-body dynamics, system design is demonstrated and improved effectively. From module or component level to assembly module, operational mechanism of system is validated. And fragile part of system

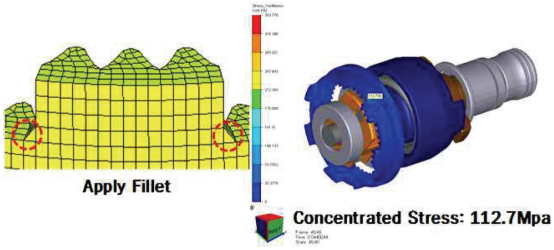

Figure 10. Stress level of improved design with fillet

is analyzed with stress level. Consequently, the design is modified by feedback and evaluated systematically with respect to specifications.

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