

A Development of the Virtual Design System for the Attachments of a Hydraulic Excavator

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ABSTRACT

The main functions of excavator are mainly carried out by excavator attachments which are composed of arm and boom. Because the core design factors of excavator such as cost, fuel efficiency and working performance are highly depends on the attachments, the attachments should be designed as light as possible. However the fatigue safety of the attachments should be guaranteed because the excavator is operated under very harsh working environment. In this paper, the virtual design system for the optimum design of the attachments considering light-weight and durability is introduced. The system enables the designer to implement attachments in a relatively short time following automated design procedures. The procedures are composed of mainly 4 parts, which are automated FEM (Finite Element Modeling), stress analysis, fatigue life calculation, optimization for the shape and the thickness. All those parts are integrated to evaluate the initial design and to optimize in view of durability and light-weight.

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INTRODUCTION

Virtual product design with numerical method gets more and more important in order to save the cost and time in fields of construction equipment. And the need to reduce the development time and increase the quality and consistency of simulation results tends to increase. An attachment of the hydraulic excavator which determines its working performance is the most dominant design factor. The design of the attachment has great influence on fuel efficiency and durability of the equipment. Thus light-weight design of the attachment should be achieved. However it is not easy to evaluate the durability of the attachments virtually. It repetitively operates under various and severe loading environments. Moreover welded structures of which an attachment is composed have an uncertainty of fatigue assessment. Most studies related to an excavator have been focused on dynamic analysis of the motion[1]. The studies on a design considering durability analysis simplified loading conditions or fatigue assessment approach[2]. Simplified loading conditions, such as maximum operating force at a certain posture have limitation to express a realistic fatigue life.

In this study, the virtual design system for the attachments of a hydraulic excavator is developed. It includes several procedures for the optimum design considering durability and light-weight. This paper is categorized in three chapters. In

first chapter, durability assessment method for the attachments is proposed: flexible multi-body analysis(FMBD) determined stresses at all locations of components for a complete operating cycle in time domain. And fatigue assessment in vicinity of welded joints was carried out using modally based durability analysis. Optimization is performed based on damage distribution. Second chapter introduces the integrated process automation system which is made to reduce the duration of the analysis process. Whole analysis processes are implemented in this system with customized user interface. It results in significant productivity. Last chapter concerns the optimum design results of the attachments considering durability and light-weight.

DURABILITY ASSESSMENT METHOD

1. Fatigue Loading

The hydraulic excavator considered in this study is shown in [Figure 1](#). Its attachments are composed of three parts: boom, arm, bucket. These parts controlled by hydraulic components independently have 3 degree of freedom system. The equipments are mainly used to move material in applications on the subject to civil and industrial field. A hydraulic excavator operates with various combination of the

attachment parts. The loads on the attachment parts are not only the constant magnitude but also the same direction. Thus it is hard to define the fatigue loading for the fatigue assessment. There were several conventional definitions of the loads for the fatigue life prediction, which are commonly types of constant vectors, e.g., maximum digging force which is defined in ISO or SAE standards. The fatigue analysis has been evaluated by the static analysis result to which these constant loads were applied. However, these approaches have some difficulties in considering realistic structural behavior because of the assumption of loading. In this study, the loading history during operation of the hydraulic excavator was applied in order to assessment the reliable fatigue life.

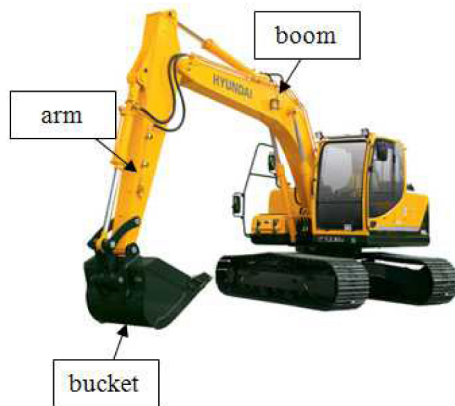


Figure 1. attachment of hydraulic excavator

2. Dynamic simulation

In order to simulate the motion and the structural stress behavior of the equipment, Flexible multi-body dynamics(FMBD) analysis was carried out. FMBD is the hybrid method that is able to simulate both rigid body dynamics and flexible body simultaneously. In order to simulate the large dynamic problem efficiently, degree of

freedom(DOF) of the flexible body which has a lot of nodal DOF should be reduced. Craig-Bampton method, which is one of the Component Mode Synthesis (CMS) methods, divides the constraint mode and the normal mode and reduces DOF of the flexible body[3].

To describe real structural stress behavior, the external forces which result from interaction between the attachment and material should be applied to the dynamic model. However it is hard to define the external forces history by a sensor such as load cell on bucket in field test. Thus the external force was numerically calculated from the cylinder length and pressure which are measured in field tests. The cylinder forces are transformed to the external force acting on the bucket tip. The equivalent external force has equilibrium of each component at every analysis step and is expressed in the type of time history

A summarized procedure is shown in Figure 2.

Figure 3 shows the strain history of the measurement and the simulation during one digging cycle operation of the excavator[4]. It is seen that the FMBD analysis to which the equivalent external forces are applied can describe stress history quite satisfactorily.

3. Fatigue assessment

In attachment, the most dominant failure is fatigue crack in vicinity of weld joint. Therefore, it is important to guarantee sufficient fatigue life of weld structure. IIW recommendation includes several assessment approaches: nominal stress, structural stress, elastic notch stress[5].

Nominal stress approach which is still prevailing in design step requires the definition of nominal stress and the corresponding classified welding details. Standards, e.g., IIW categorize weld joints according to welded structure detail. However, this concept is not available in case of complex structure, in which neither nominal stress nor appropriate weld detail cannot be defined. Structural stress concept, one of the local stress approaches, overcomes the ambiguousness

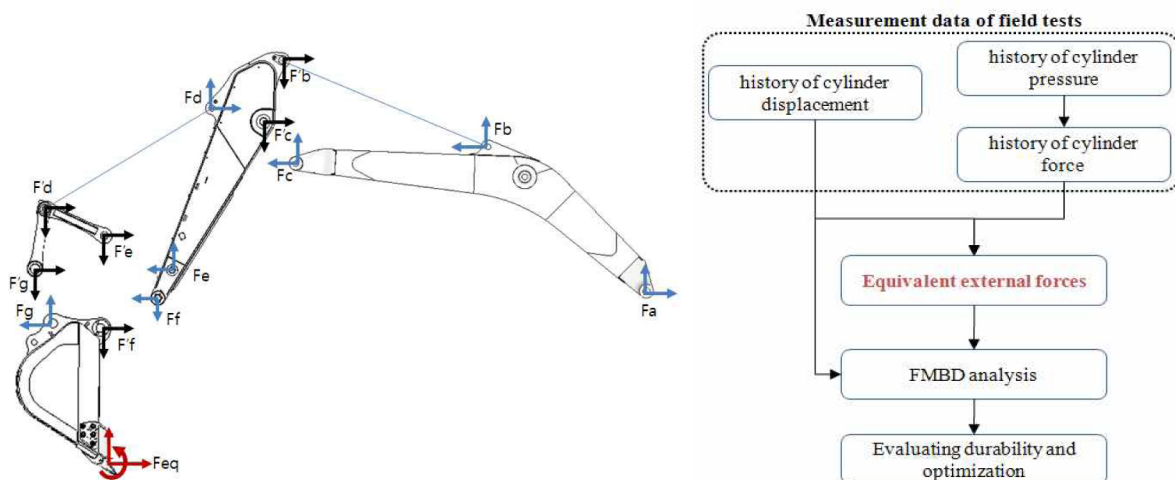


Figure 2. equivalent external force