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EXPERIMENTAL VALIDATION OF A MAGNETORHEOLOGICAL FLUID ACTIVATION FLOW CFD ANALYSIS

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Abstract

High-speed operation of magnetorheological (MR) fluid flow-mode devices can lead to a phenomenon known as high-speed yield force falloff. This occurs when the yield force, the difference between the field-on and field-off forces, decreases as the active-gap velocity increases. This behavior has been observed in various applications like high-speed capillary rheometer tests, impact absorbers, and seismic dampers. However, this phenomenon is not predicted by existing yield force models, which predict either an increasing or constant yield force with increasing speed.

Existing force models of MR fluid flow-mode devices are based on oversimplified fluid dynamics. These models have determined the yield force by assuming a 1-D velocity profile and ignoring fully developed Newtonian losses. Then, to obtain the field-on force, the field-off force is first obtained and then constant yield force is added to the field-off force. This methodology is useful for designing MR fluid flow-mode devices when simplicity and productivity are pursued as a top priority. This design procedure makes accurate field-on force prediction at low speeds, but field-on force prediction at high speeds becomes inaccurate because the nonlinearity of fluid dynamics increases as speed increases.

In our previous study, we developed an activation flow model which was a simplified 2-D computational fluid dynamics (CFD) model of a duct to address this limitation. In the activation flow model, fully developed Newtonian flow enters a region of uniform yield stress with a constant yield stress fluid flow. This simplified CFD model captured the fluid dynamics of flow-mode devices operated at high-speed controllable yield stress fluid flow. Control volume analysis of activation flow analytically demonstrated that the main cause of high-speed force falloff was a change in momentum flux arising from the velocity profile of the plug (the central core of constant velocity fluid). In this study, we validate the activation flow model by identifying the performance of a practical flow-mode device that operates in a high-speed regime. To this end, an impact absorber designed in our other previous study was selected and its high-speed yield force falloff is accurately predicted by the activation flow model. These results demonstrate the model's ability to accurately predict the yield force of MR fluid flow-mode devices at high speeds, providing a robust understanding of the design space of MR energy absorbers.