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Direct driven hydraulic drive for new powertrain topologies for non-road mobile machinery

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ABSTRACT

Tightening of emission rules and a desire to improve energy efficiency pushes even further the need for hybridization of non-road mobile machinery (NRMM). Consequently, this paper illustrates potential of the application of directly driven hydraulic drive (DDH) for NRMM from an energy efficiency point of view. The control of the DDH system was implemented directly with a servomotor driving a pump without conventional hydraulic control valves. Angular speed of the servomotor, in-coming oil flow from the pump, and out-going flow to the hydraulic motor determined the velocity of the double-acting cylinder piston. An earlier study by the authors presented that the hydro-mechanical losses were dominant in the original DDH setup. Resulting theoretical investigation indicated that the best scenario efficiency for DDH was estimated to be 76.7%. Therefore, this paper provides a detailed analysis based on Sankey diagrams of various powertrain topologies with DDH. This study of powertrains illustrated that DDH has the highest impact with 174% efficiency improvement with an electric NRMM powered by batteries instead of a conventional topology.

1. Introduction

Energy efficiency is becoming crucial in all fields of engineering as a result a tightening of emission rules [1]. At present, valve-controlled hydraulic systems with throttled pressure, losses and lower efficiency are applied commonly in Non-road mobile machinery (NRMM). Currently, industry is investigating for compact, efficient and powerful solutions for control and powertrain applications in NRMM. Similar demands are recognized in industrial hydraulics where a flexible layout of production, lower energy demand, and avoidance of additional heat and noise. New technological solutions are needed to further reduce fuel consumption and improve energy efficiency to fit new governmental requirements. Hybrid technology has been identified to be one of the key solutions to achieve these targets. There are already some examples of NRMMs in the market that provide hybrid solutions [2,3]. In these, the hybridization targets mainly in improving performance and fuel economy. In [4], a 20-ton parallel hybrid excavator by Komatsu with supercapacitor achieved up to 41% energy savings. A Hitachi serial hybrid loader with a battery as energy storage achieved energy savings of 25–30% depending on the cycle [5]. Typically, the diesel engine is running hydraulic pumps and the mechanical powertrain. In these, the diesel can be supported by electric motor/generator located after the diesel engine. In [6] the challenges faced by researchers and NRMM manufacturers were underlined, such as energy storage, control of generation energy and cost in general. These provide new dimensions into the control of generation and distribution of electric energy. On the other hand, the development of an electric and plug-in powertrain proposal for NRMM is facing identical problems in the automotive sector related to battery technology and its charging issues. In electric vehicles – especially passenger cars but also busses – there is now urgent need to define charging systems and develop needed infrastructure. Recent research concentrates on charging of electric vehicles [7–9], as this is essential in order to ensure wider acceptance by customers and facilitate more electric vehicles on roads. This need is underlined also by politics in EU.

Before these solutions enter wider markets, it can be hypothesized there will be a need to have even more sophisticated means to utilize electric energy for creating hydraulic pressure on board and only when it is required. Currently, a trend for a decentral-

Abbreviations: DDH, direct driven hydraulics; NRMM, non-road mobile machinery; SOC, state of charge.

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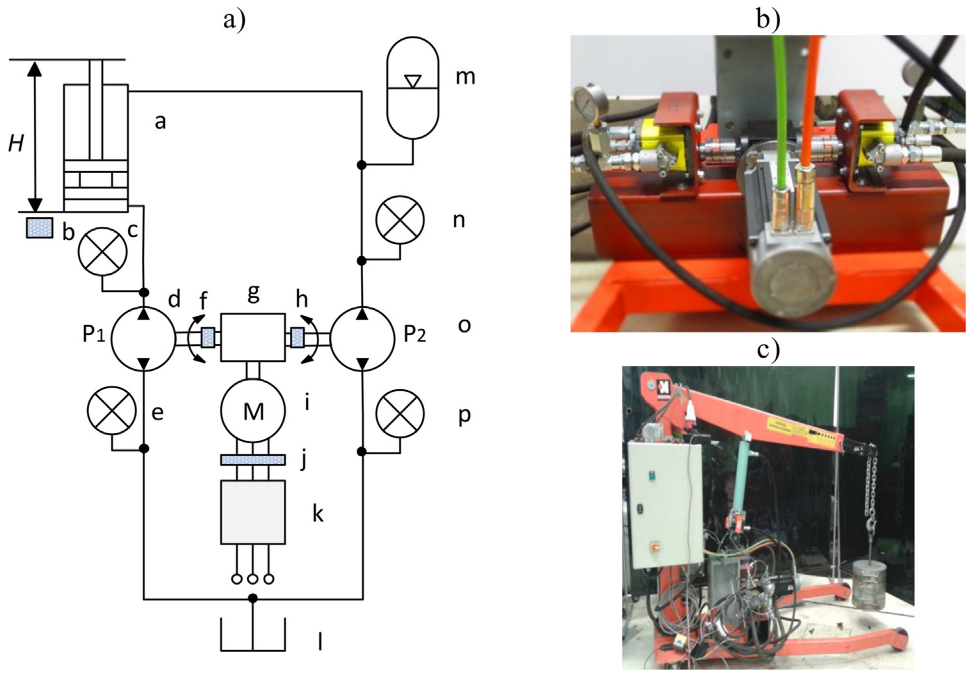

Fig. 1. DDH (a) Simplified schematics of the test setup: a—double-acting cylinder, b—wire-actuated encoder, c—pressure sensor, d—reversible gear pump/motor P_1, e—pressure sensor in tank line, f—torque sensor, g- T-gear, h—torque sensor, (i) PMSM motor/generator, j—current and voltage probes, k—frequency converter, l—oil tank, m—hydraulic accumulator, n—pressure sensor, o—reversible gear pump/motor P_2 and p—pressure sensor in the tank line. *Sensors are utilized for system diagnostic purpose only. (b) PMSM motor/generator connected through T-gear into two internal gear motor/pumps [20], (c) experimental setup.

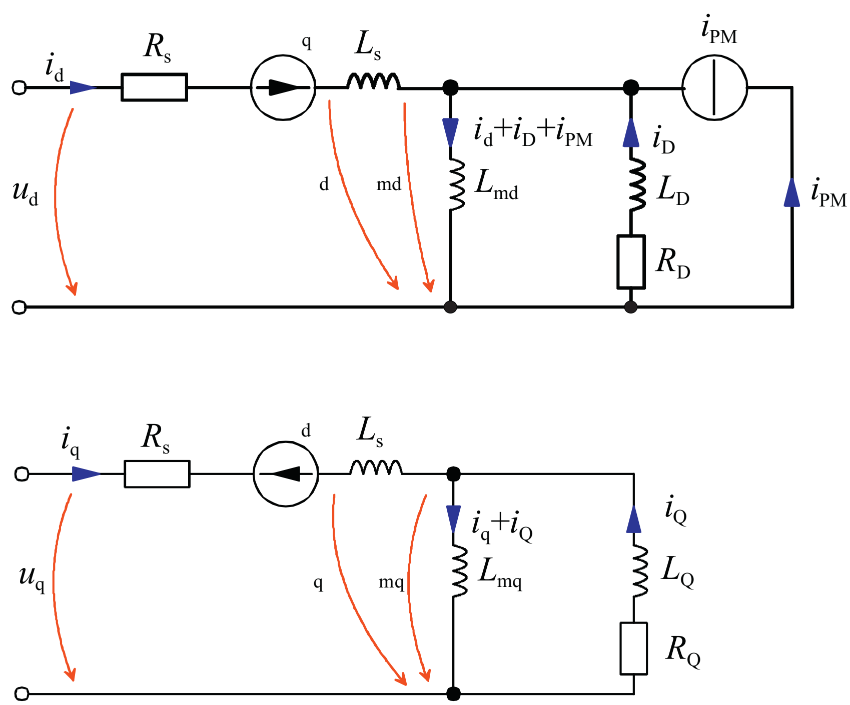

Fig. 2. Equivalent circuits of circuits of PMSM [25].

ized power network opens up new approaches for hydraulic- and hybrid circuits for NRMM [10–12]. As a result, electro-hydraulic systems with motor- or pump-controlled systems are observed on the market and research areas [13–18]. These electro-hydraulic systems are attracting an attention of industry due to advantages of their size-to-power ratios and the ability to produce large force and torque only on demand. These technologies provide opportunities, compared with traditional systems, a compact structure and high efficiency with a speed regulation loop without conventional valves [19,20]. All these features can be beneficial in creating new powertrain topologies in NRMM.

Consequently, the development of electro-hydraulic compact systems motivates current research activities, however no efficiency analysis was found concerning their application in the NRMM systems. Therefore, the effect of a direct driven hydraulic setup (DDH) on the efficiency of a variety of powertrain topologies