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A study on an underwater tracked vehicle with a ladder trencher

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ABSTRACT

Understanding the trencher interaction through analyses on the design and mechanics is essential for autonomous and operations of underwater tracked vehicles (UTVs) with a ladder trencher (LT). The objective of this paper is to analyze the mechanics of the UTV system that are affected by LT force and moment. For this, the force and moment on the cutter bar based on the analysis of the mechanics of the individual cutting tool are determined. Also, the mathematical expression is derived for the force and moment of the combined system of the UTV and LT for trencher tool cutting of the soil. For this, the parameters that affect the mechanics of the combined system are studied. For applying the trencher system to underwater soil cutting, the hydrostatic effect of buoyancy force is also studied.

For the design of the UTV system, the required tractive thrust or normal reaction force was analyzed, and the moment to the rotor carriage caused by the cutting system is studied. In addition, analysis on the energy and power for the cutter bar actuator related to the tool characteristics is performed.

To support the validity of the analyses, a number of numerical simulations are performed using the derived equations.

1. Introduction

It has been commonly accepted that trenching of pipelines will substantially reduce both hazards to the pipe and ones caused by the pipe. The UTV is the specialized equipment for water trenching operations to hide a pipeline underground. The offshore industry is looking for reliable solutions for the protection and stabilization of any type of submarine line: Cables – Flexibles or Rigid Steel Pipes, installed on the sea bed. Laying the line in a trench is presently one of the preferred methods. The technique described in this paper concerns trench cutting. The types of equipment used for trenching of pipelines include jetting machines, mechanical trenchers (mechanical rock wheel cutters or mechanical chain excavators). Each of these uses quite different techniques to excavate the trench: the water jet tools employ jet nozzles to erode or liquefy the soil and the mechanical cutters reply on hardened picks-largely developed in the mining industry-to cut the soil or weak rock.

The trencher system is designed to meet the needs of the underwater power and telecommunication industries, providing reliable solutions in trenching operations, especially in shallow and near-shore operations. The proposed system consists of a trenching tool connected to a tracked vehicle, which is lowered to the sea bed by a crane. The tracked vehicle receives electrical power from the surface through an umbilical cable. A trencher is a machine that uses a rotating cutting chain equipped with bits to excavate trenches in rock and soil for underground cables and pipelines. The proposed trencher machine is compact and versatile and with the combination of various trenching tools such as ladder trencher tool/wheels-rock crusher tool, excavation under difficult conditions is made possible without compromising the safety of the cable system. Different tooling options are a new feature of this vehicle to enable burial to increased burial depth requirements. Equipped with the cutting wheel trenching through rocky or extreme hardness soils is feasible, even in uneven territories. The performance of such machines is limited by the traction available from the tracked vehicle, with the trenching depth being at the maximum obtainable in soil. These factors depend on both the properties of the excavated soil material and the trencher characteristics.

For the seafloor miner, tracked vehicles are compared to wheeled or legged vehicles due to the larger contact area of tracks with the ground providing better floatation and the larger traction forces, which are required for the extremely cohesive soft deep-seafloor soil. In this reason, the interaction between ground and off-road vehicles, such as

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agricultural tractors, has been important field of study (Muro and O'Brien, 2004). In order to investigate the performance of tracked vehicles, a number of studies have been carried out. Wong (1989) developed an analytical method for predicting the normal pressure distribution under a moving tracked vehicle, taking into account the response of the terrain to repetitive shear loading. Rubinstein and Hitron (2004) developed a three-dimensional (3D) multi-body simulation model for simulating the dynamic behavior of tracked off-road vehicles using the LMS-DADS simulation program and used user-defined force elements to describe the interaction between each track link and the ground. Solis and Longoria (2008) described integration of a realistic and efficient track-terrain interaction model with a multi-body dynamics model of a robotic tracked vehicle, and comparisons between simulated results and those obtained from field testing with a remotely-operated unmanned tracked vehicle. Hong et al. (2002) developed a simplified transient 3D dynamic analysis method for tracked vehicles crawling on extremely soft cohesive soil. Ai-Milli et al. (2010) realized that the turning maneuvers of the tracked vehicle on soft soil will lead to overly high slip and immobility, and presented an analytical approach to track-terrain modeling and a novel traversability prediction simulator for the tracked vehicles conducting steady-state turning maneuvers on soft terrain. Neil and Cathie (2007) discussed aspects of terramechanics and mobility that are applicable to the operation of tracked trenchers on very soft clays, in addition to demonstrating a rational approach to determining trencher mobility in very soft soils.

The LT machines are able to perform vertical and horizontal cuts for quarrying natural stone mine. These machines are able to excavate on natural soil or rock using tools with screw clamp, and work with or without water. Few studies have been published in the literature related to predicting the performance of LT machines. Mancini et al. (1992, 1994) analyzed the parameters affecting the chain saw machine performance and the chain cutting was geostatistically simulated. The in-situ chain saw applications were analyzed by Mancini et al. (2001) in terms of cutting performance, tool wear rate and stone parameters. Primavori (2006) investigated the operational conditions of chain saw machines so as to understand the effective usage of these machines. Sariisik and Sariisik (2012) investigated the cutting performance of a chain saw machine. The obtained cutting results were compared with diamond wire cutting results.

The basic physical phenomenon occurring during cutting is soil desintegration under mechanical action of a cutting tool. Design of cutting tools and setting parameters of cutting operations requires knowledge about the cutting process. Cutting force is one of the main factors characterizing a cutting process. Theoretical evaluation of the cutting force is not an easy task. The mechanical interaction between the tool and soil has been studied by numerous researchers over the years. The primary motivation behind these research efforts is two-fold: on the one hand, the need to improve the efficiency of mechanical excavation of soils, and on the other hand, the possibility of deducing material properties from the action of a tool pressed against the surface of a soil. Simple analytical models, like those developed by Nishimatsu (1972), can provide a very approximate estimation of cutting forces only. Hartog et al. (1997) developed a knowledge-based fuzzy model for the performance prediction of a rock-cutting trencher. Inyang (2002) performed an analysis on parameters that impact the energy expenditure of the excavation for trenches and chambers in rock. Huang (1999) studied discrete element modeling of tool-rock interactions focusing on establishing scaling laws between the phenomenological parameters of a material and the properties of a discrete disc assembly.

However, until now, previous studies still exist a knotty problem that how to implement the dynamic analysis of the total deep ocean mining system, since modeling excavation performance using soil properties is difficult. The dynamic interaction between cutting tools and the soil mass is uncertain, complex and difficult to describe. So, new efficient and reliable modeling methods for the LT tool and further for the total system should be considered and developed. Furthermore, the influence factors acting on underwater LT tool are very complicated; unfortunately, the effects are not fully studied and carefully analyzed; sometimes important factors are neglected. Thus analyzing the reaction of underwater LT tool to UTV is very important; it is the focus of this paper.

This paper develops theoretical equations for the geometry and motion of the continuous belt machines used for cutting and excavating. After a listing of the definitions of the relevant technical terms, the analysis begins with the development of the relations linking speed of the belt, traverse speed, chipping depth, cutter spacing, and inclination of the belt. Typical values of these parameters for the industrial machines are given, and graphical summaries are provided for these values of the speed of belt and traverse speed. The main aim is to encompass the full mechanics in an equation relating the force of the trencher to the UTV. To achieve this, forces from individual cutting tools were analyzed when they were mounted on a trencher tool, and this information was used to determine how an assembly of tools affects the moments and forces of the entire cutter bar. This leads to estimates of the required thrust or the reaction along the direction normal to the traverse plane. The design of the rotor carriage was also studied by considering the moment caused by the cutting system since this affects both the weight and balancing force of the UTV. Finally, a number of the simulations were performed to generate physical values for the design of the system.

2. General specifications of the underwater trencher system

2.1. The trend of underwater trencher system development

There are a diverse range of cable burial machines available around the world in the market capable of burying and protecting offshore cables. These types of vehicles are generally divided into two sub-groups: Tracked Vehicles for Shallow Water Use (usually within the range of air divers); and Tracked Vehicles for Deep Water Use (in water depths up to 2500 m). Table 1 describes a range of tracked cable burial vehicles which are currently available in the marketplace.

According to Table 1, underwater trencher system is classified into three types of burial tools which are commonly fitted to tracked cable burial vehicles as follow.

- Jet trenching systems;
- Mechanical rock wheel cutters; and
- Mechanical chain excavator.

In this paper, the proposed trencher machine which belongs to mechanical chain excavator and mechanical rock wheel cutters is similar to the one named "TM 02" which is listed in Table 1. The proposed trencher dimensions are 5.7 m long, 0.5 m wide and 4.15 m high, the weight is 29430 N in the air without the water ballast and maximum burial capability of the trencher is 2 m. Fig. 1 shows a shallow water tracked cable burial machine which is fitted with a LT tool, but has the flexibility to interchange a rock crusher tool if required..

2.2. Underwater trencher system description

The proposed system consists of a trenching tool connected to a UTV, which is lowered to the sea bed by a crane as shown in Fig. 1. The UTV receives electrical power from the surface through an umbilical cable. An LT tool is a machine that uses a rotating cutting chain equipped with cutter tools (bits) to excavate trenches in rock and soil for underground cables and pipelines. The cutting unit consists of a cutter bar and a chain with drag cutter tools (bits) spaced along its length and wound around the cutter bar. The cutter bar is hinged at the tractor end and can be lowered into a trench for continuous cutting. To