Optimisation of OFD®-Shaft Sinking Machines by holistic system-simulation

energy-efficient preliminary design based on virtual prototypes

Dipl.-Ing. Mathias Näther,
Prof. Dr.-Ing. habil Günter Kunze
Technische Universität Dresden
tu-dresden.de

Boris Jung

Herrenknecht AG, Schwanau
www.herrenknecht.com

Offshore Foundation Drilling (OFD®) is a new foundation technique to build groundings for offshore wind turbines more environmentally friendly and economically in the future. In parallel to the development of the machine technology the ENPROVI simulation method is used to facilitate the energy-efficient tuning of the drive system by power flow analysis.

Offshore Foundation Drilling - OFD®

Expansion in renewable energy sources is essential to be able to achieve the Federal Government's climate protection targets. Especially the increase of offshore wind energy is important in this context. The establishment of fundamental structures, typically monopile, tripod or jacket structures is a task that poses a major challenge to the implementing companies. For this reason, Herrenknecht AG in collaboration with Hochtief Solutions AG have developed a new foundation method, Offshore Foundation Drilling - or OFD® for short (**figure 1**). It involves the use of drilling technology to install the foundations on the seabed. The drilling method offers major benefits in comparison to legacy pile-driving technology:

- Geology-independent: adaptation of the tooling on the cutterhead means that any geology, from sand to solid rock (80MPa) can be penetrated.
- Low noise: forecasts for noise emission of this drilling technology are approx. 120dB re1µPa at a distance of 750m, which is considerably below the legal requirement. This removes the need to adopt special noise protection measures.
- Universally deployable: the machine can be used for monopiles with diameters between 5.5m and 7.5m.

The method involves running the plant technology from a jack-up vessel. The vessel lifts itself out of the water on jacks and then erects the monopile. After the monopile has been positioned and lowered to the seabed, the drilling machine is inserted into the pile and lowered to drilling depth. The machine then clamps via hydraulic cylinders and centres itself at the same time. Three electric motors with a total output of 750kW drive the cutter head. The geology loosened by the cutter head is extracted from the ambient water within the cutter head by a suction nozzle and discharged by two feed pumps with a drive output of 550kW each. The soil/water mix is pumped onto the jack-up vessels deck, wherefrom it is fed to a separating plant on another vessel. The overall system has a total power draw of around 3,600 kVA. This power is produced by several diesel generators.

Figure 1: OFD®- foundation method (a) and OFD®-machine (b)

ENPROVI simulation method

To optimise the OFD®-machine with regard to its power requirements, an energy efficiency analysis using SimulationX is created in parallel to the systems engineering in cooperation with Dresden University of Technology. The approach for the model creation is based on the ENPROVI-method, which is a result of the corresponding research project that was initiated by TU Dresden and ITI GmbH in 2009. The characteristic features of this method are the modular structure of the simulation model on the one hand and the basic subdivision of the model into the two coupled subareas “reference machine” and “reference process” on the other hand [1]. A further result of the ENPROVI project is the implementation of the “power balance” tool in SimulationX, which makes it easier to create a power balance for the whole simulation model. By means of the automatically generated power variables, the power flow along the individual model components can be investigated subsequently and energetically critical elements can be identified. The user is now able to match the drive system welldirected to the machine-specific work profile, whereby the efficiency of the whole system can be increased.

General structure of the simulation model

The machine model is developed considering the requirement to map the system behaviour of the OFD®-machine in terms of its power flow. It has not the intention to provide more detailed results, like e.g. the dynamic behaviour of the mechanical drive train. Thus, some simplifications are assumed with respect to the named restrictions:

- Only process-relevant machine components are part of the model.
- The mechanical transmission is mainly treated as an ideal stiff system.
- The components of the electric drive are modelled without using types from the “electricity” library.

Figure 2 illustrates the structure of the OFD®-model, based on the ENPROVI-method. It is assembled by plenty of individual compounds, which are interacting beyond their system boundaries via connection variables. Most of the elements are allocated to the ENPROVI-section “reference machine”. These elements are used to simulate the drive train of the OFD®-machine and finally to calculate the power balance. In the section “reference process” a load input function, based on a machine-specific process pattern, is generated and impressed to the MBS-model by forces and torques. The MBS-model represents the mechanical structure of the OFD®-machine. It is used to include the inertias of the moving machine parts and to generate a kinematic transfer function as an interface between the process model and the onedimensional machine model. The timing of the system simulation is influenced by the module “simulation control”. This module records different state variables from the simulation sequence, initiates determined simulation phases and thus actively interferes in the calculation process.

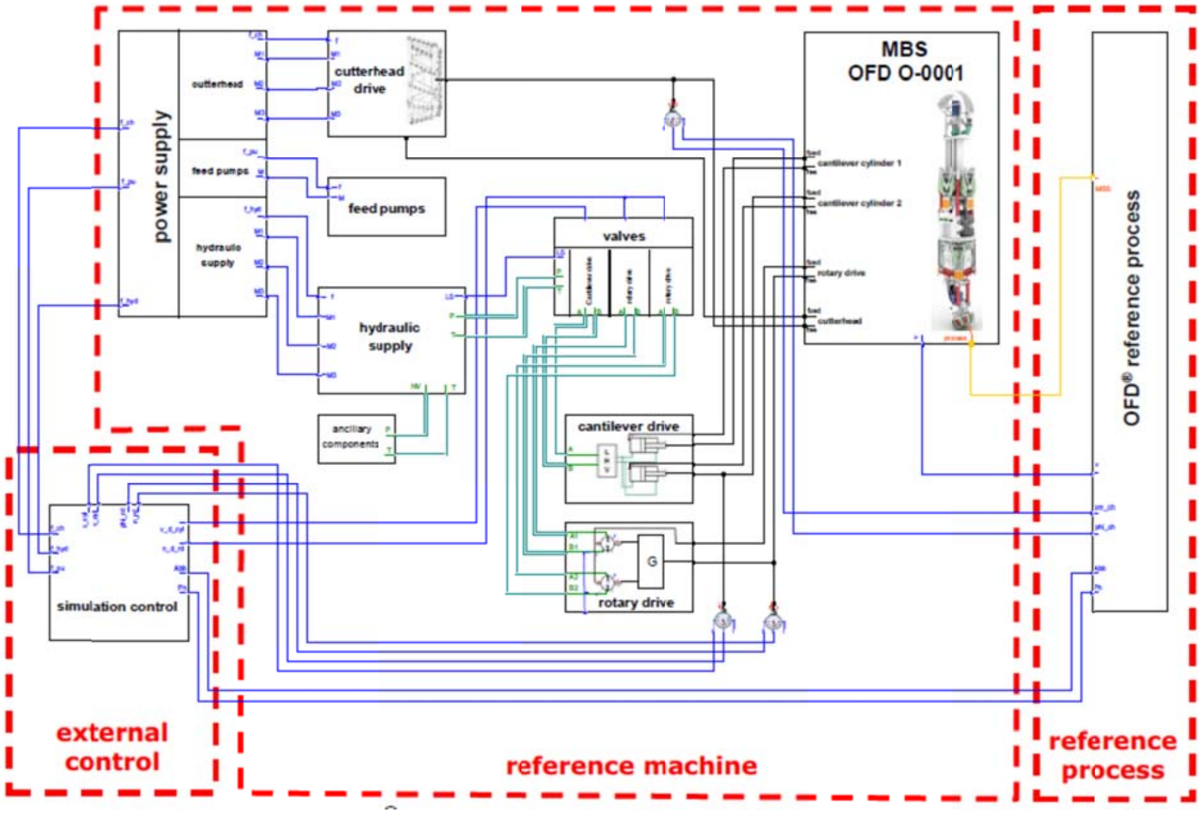

Figure 2: Structure of the OFD®-simulation model, based on the ENPROVI-method

Using the example of the cutterhead-drive, **figure 3** shows the hierarchical structure of the OFD®-model. The cutterhead is driven by three frequency controlled induction motors, whose power is transmitted by a summation gear. The compound “cutterhead-drive” contains the model of the mechanical drive train, which is treated as a stiff system with regard to the previous mentioned simplifications. The models of the induction motors are realised as subsystems of the next lower model level. Therein the motor is modelled as a torque source, whose torque is determined by different signal blocks according to the current model variables. The motor performance maps stored in the signal blocks are externally calculated on the basis of common formulas [2] and loaded into the model during parameterisation. This way it is possible to model a frequency controlled induction motor in a simple manner, while keeping the calculation time low.

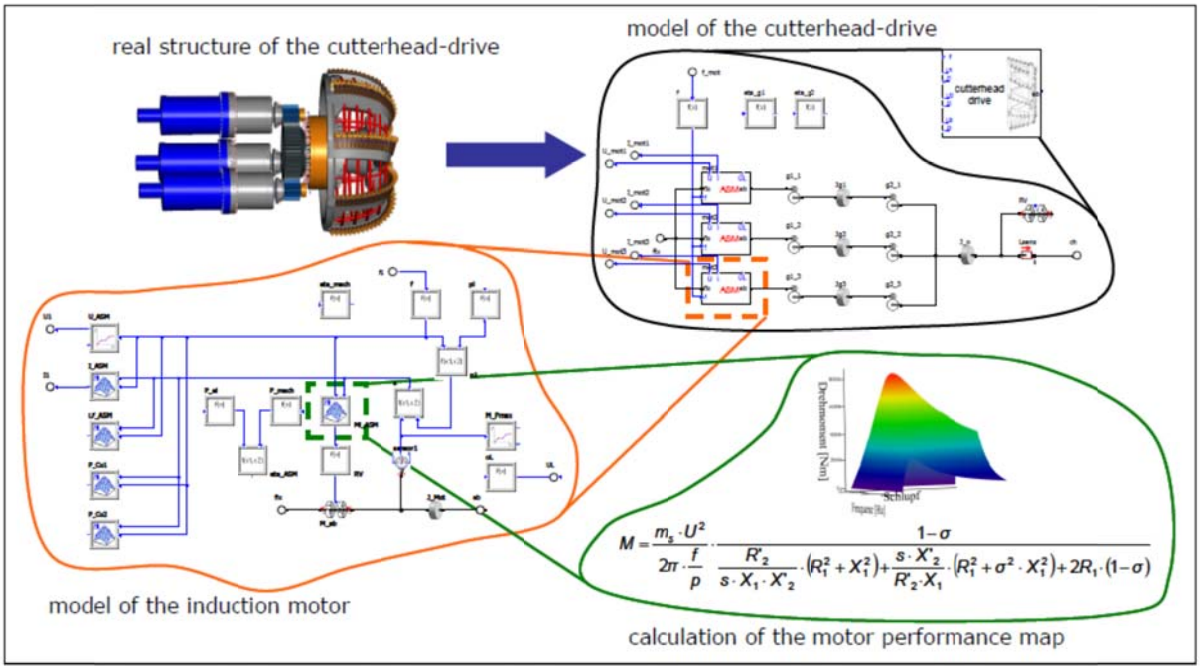

Figure 3: Subsystems of the cutterhead-drive compound

Model of the reference process

Two determinations are made for the creation of the process model. The first one defines only the sectional excavating process as the examined process pattern and excludes all the other sub-processes, which are normally part of the work flow, too. Thus, the chisel-equipped cutter head is defined as the sole interface between machine and process. The second determination comprises the imagination of an axial force, which acts on the chisel from the moment when it plunges into the geology. This axial force only depends on the geology- and headingparameters during the cutting process and is calculated by the approaches of [3] [4] and [5]. The summation of all currently acting chisel forces, with respect to their spatial components, results in a total load at the cutter head. The implementation of the axial chisel forces is conducted using MBS force elements that are acting on the bodies of the structure-mechanicsmodel, at the position of each respective chisel. Inserting the force elements manually would be ineffective because of the high number of chisels. For that reason the possibility of automatic model creation in SimulationX is used (**figure 4**). To reach the goal of automation a VBA-script has been programmed that accesses SimulationX using the COM-interface and inserts all required elements and parameters to the model in an iterative procedure. Necessary information is e.g. the corresponding position- and orientation-parameters of the force elements to the associated chisels as well as various functions for the description of the motion-dependent force curve. The spatial orientation parameters are exported previously from a CAD-model to a data table. After executing the script, the process model is created in short time and only a few further adjustments are necessary to use it as the reference process in the ENPROVI-simulation. The benefit of automatic model creation is, that the process model can be adapted easily to new requirements, e.g. different cutterhead designs, as long as the calculation base stays unchanged. Thus the ENPROVI model always gets an appropriate load input function. Moreover, the automation gives the machine designer the possibility of cutter head optimisation by parameter variation or further investigations.

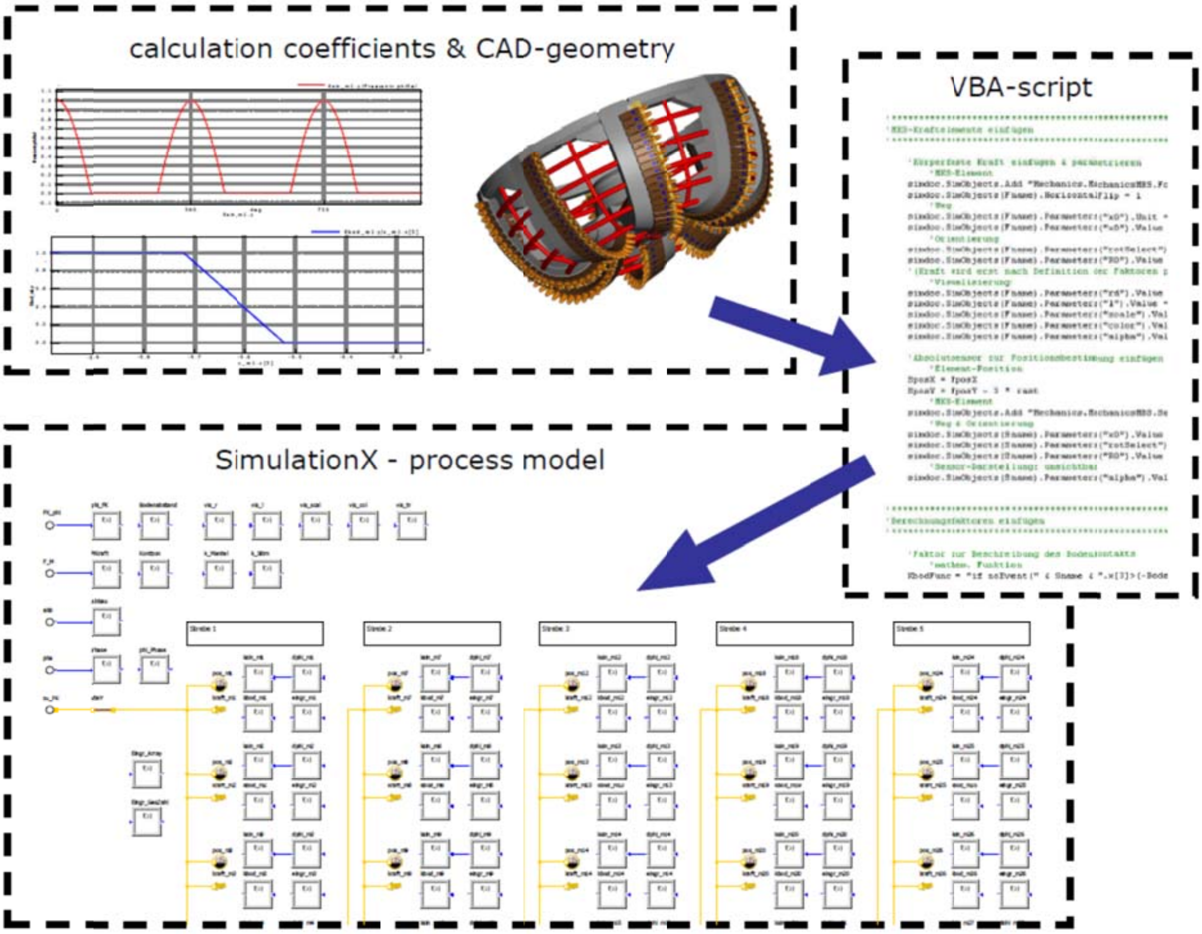

Figure 4: Script-based creation of the process model

Summary and outlook

The intention of the developed simulation model is to investigate the power flow within the OFD®-machine to gain knowledge of possible savings and optimisations of the machine technology. This way measures can be taken to optimise the power requirements already on the virtual prototype. After comparison to measured values from the initial application, the simulation results will be incorporated in the ongoing machine design process. The modular structure of the simulation model additionally offers the option to integrate already created model elements into other simulation scenarios, or to extend the energy efficiency investigations to the Herrenknecht AG product range. Future plans comprise the creation of a comprehensive model library within the enterprise and the extension of the existing model structure by implementing a graphical user interface and prebuilt evaluation routines.

sources

[1]
Th. Hentschel, G. Kunze, Th. Neidhold, B. Petack, Chr. Schramm, D. Slowik: Verbundprojekt ENPROVI - gemeinsamer Ergebnisbericht; Dresden / Lauchhammer 2012

[2]
R. Fischer: Elektrische Maschinen; 15. Aufl.; Hanser Verlag, München 2011

[3]
A. Ehler, G. Kunze: Konzepte für die Werkzeuggestaltung und -bemessung des Continuous Surface Miner. Stand der Perspektiven der kontinuierlichen Tagebautechnik. ISCSM Continuous Surface Mining. International Symposium Nr. 6; TU Bergakademie Freiberg 2001

[4]
P. Frenyo, W. Lange: Die Auslegung von Schneidköpfen für optimale Löseleistungen; Glückauf Bd. 129 Heft 7; VGE Verlag, Essen 1993

[5]
G. Kunze, H. Göhring, K. Jacob: Baumaschinen, Erd- und Tagebaumaschinen; 1. Aufl.; Vieweg + Teubner, Wiesbaden 2009

author

Technische Universität Dresden
Professur f. Baumaschinen- u. Fördertechnik

Dipl.-Ing. Mathias Näther,
Prof. Dr.-Ing. habil. Günter Kunze

D – 01062 Dresden

Tel.: +49 (0) 351 463 34567
Fax: +49 (0) 351 463 37731

e-mail: mathias.naether@mailbox.tu-dresden.de
Internet: tu-dresden.de/bft