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Marine & Offshore

Engineering around a hydraulic controlled gearbox

By Ing. T.Heeringa, Royal Boskalis Westminster N.V.

Royal Boskalis Westminster N.V. is an international service company active in the area of maritime infrastructure in fifty different countries on five continents. Besides carrying out individual projects, Boskalis has ten home markets and permanent local branches in various countries.

Introduction

This article will focus on the hydraulic controllable gearbox to drive the dredge pump on board of a hopper dredger and the induced torsional vibrations from the main engine and the dredge pump on the performance of the drive system. A model of this gearbox has been made in 20-sim and subsequent simulations are compared with measurements.

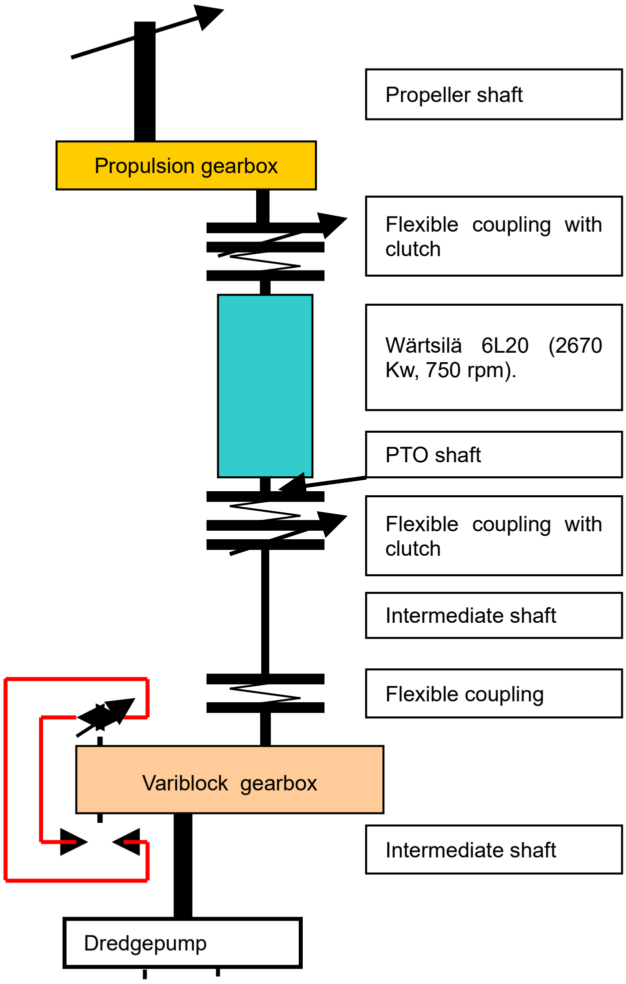

Figure 1: Drive System.

The dredge pump in the hopper dredger "Waterway" and her sister ship "Coastway" are powered via a PTO shaft from the starboard 6L20 Wärtsilä main engine. The gearbox is a two speed gearbox with a special hydraulic driven planetary gear wheel carrier in order to control the speed of the dredge pump in a limited way, when operating in speed 1 or in speed 2. Output shaft power of the gearbox in speed 1: 1500 kW, speed control of the output shaft from 190 to 240 rpm, and in speed 2: 2700 kW, speed control of the output shaft from 300 to 370 rpm.

Figure 1 depicts the configuration on board of the two hopper dredgers. The main engine with on its flywheel side a flexible coupling with a clutch and the propulsion gearbox with the propeller shaft and the controllable pitch (CPP) propeller. On the other side of the main engine (see figure 1) there is a PTO shaft and mounted on that shaft is a flexible coupling with a clutch, an intermediate shaft, again a flexible coupling and then the variblock gearbox, again an intermediate shaft and then the dredge pump.

The flexible couplings are used to protect the gear wheel from the failures due to torque fluctuations from the diesel engine and to allow some movements between diesel engine and gearbox because of the limited stiffness of the ship.

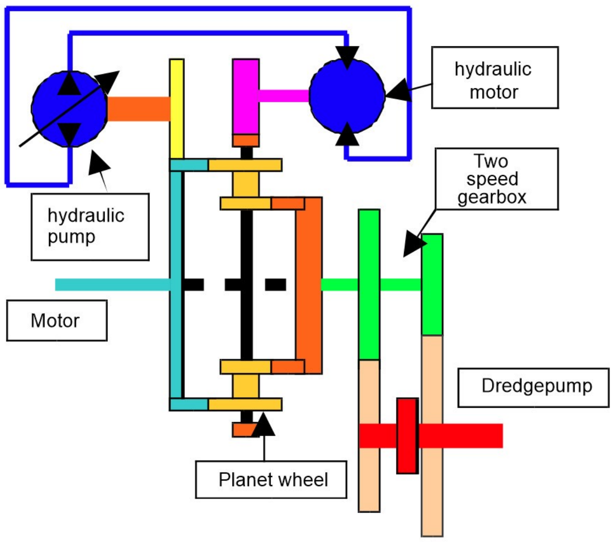

Figure 2: Physical system of the dredge pump drive.

Figure 2 depicts a schematic diagram of the physical model of the complete drive system of the dredge pump. Attached to the gearwheel on the input shaft of the gearbox, there are two hydraulic pumps working in a parallel configuration. The output of the pumps is variable in two directions, so the power flow through the pumps is also in two directions. The pump feeds in a closed hydraulic loop two low speed hydraulic motors, also in a parallel configuration, to control the planetary gear wheel carrier speed. When the swash plates of the hydraulic pumps are in zero position, the planetary wheel carrier is at standstill and the dredge pump will have the same speed as the gear box input shaft, times the gear ratio of speed 1 or speed 2. By changing the position of the swash plates and so the

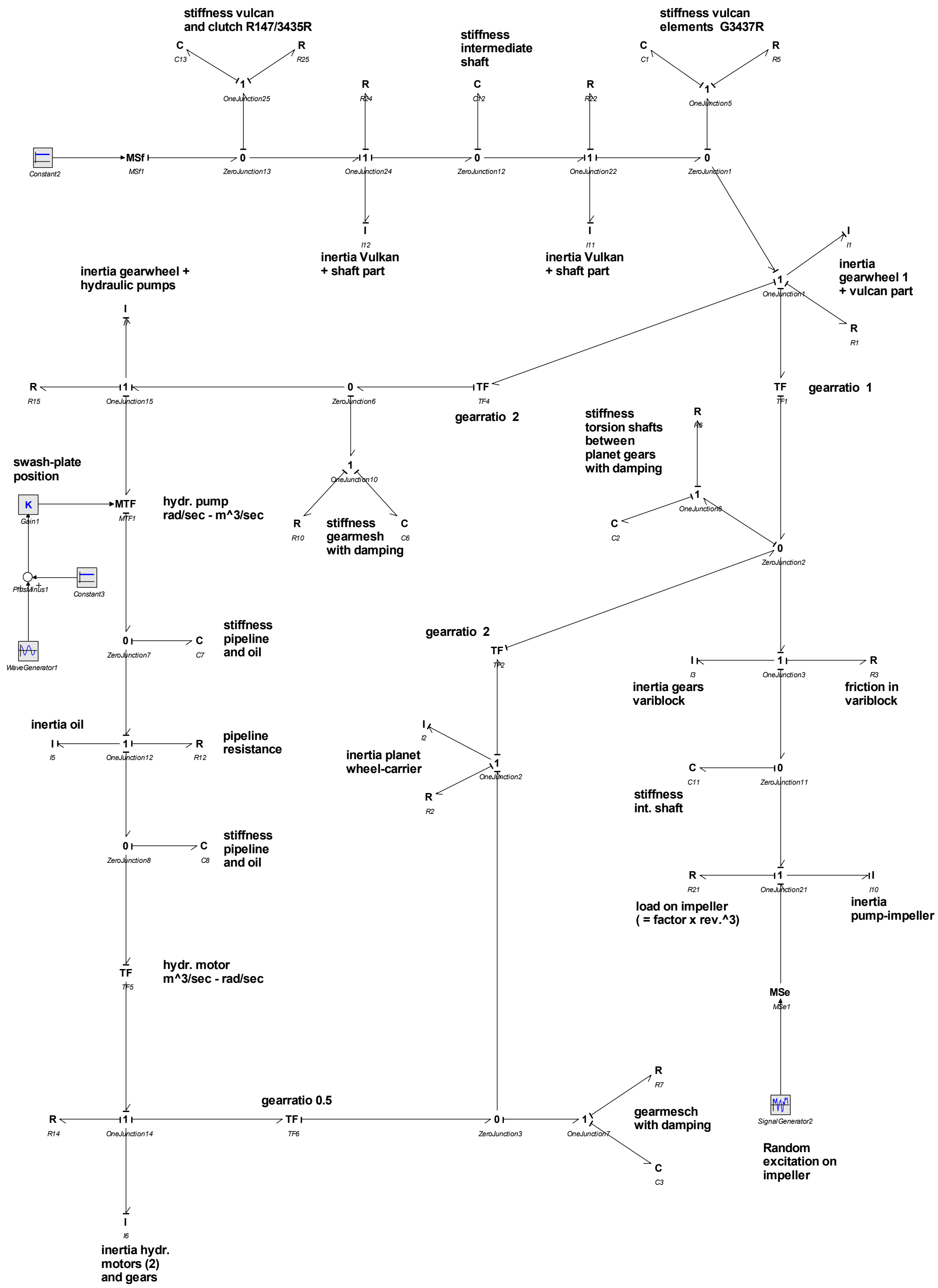

Figure 3: The bond graph model of the dredge pump drive entered in 20-sim.

volume flow of the hydraulic pump to the hydraulic motors, the speed of the planetary gear wheel carrier will change. This speed is added or subtracted from the speed of the gearbox input shaft resulting in a higher (or lower) speed of the dredge pump. The drive system was originally designed without a thorough dynamic analysis. A dynamic model has been created after the design and construction of the system, to find out if the resulting simulation could lead to a more optimized design.

Model

From the physical system of figure 2, a Bondgraph was developed depicted in figure 3. The diesel is modeled as a flow source. The elastic coupling is modeled as a spring with damping. When torque is applied to this type of coupling, the resulting torque-angular

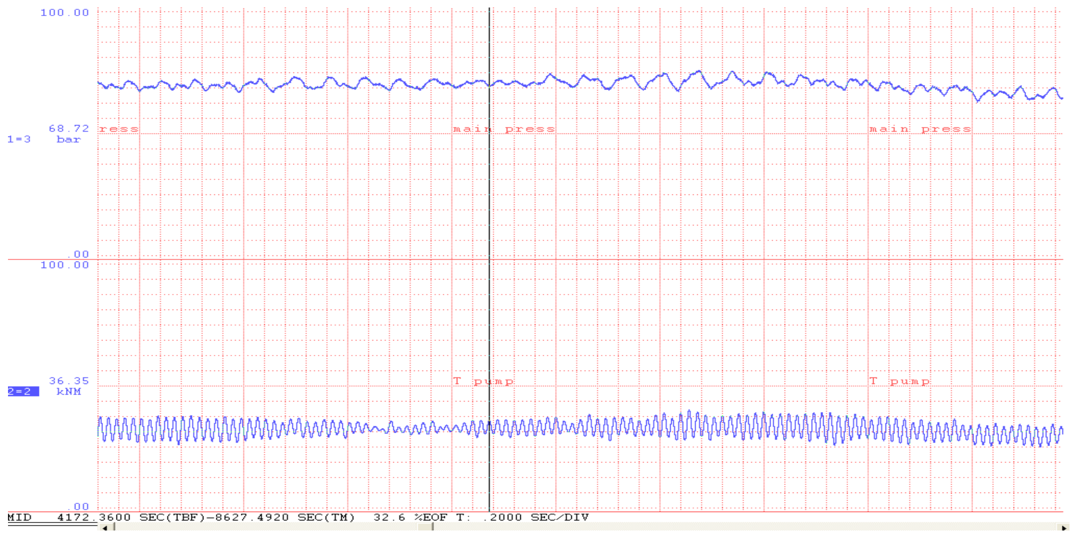

Figure 5: Measured pressure and dredge pump shaft torque during dredging.

Figure 4: FFT analysis of the measured hydraulic pressure from figure 4.

deflection characteristic is linear and in addition to the linearity a hysteresis characteristic is exhibited. This means there is damping associated with the coupling. For this particular study the damping is not that important and is simply modeled as a resistor: R5 and R25.

The input power to the gearbox is split up inside the gearbox in a "mechanical part" and a "hydraulic part", the bond graph has also a "mechanical" and a "hydraulic part". The mechanical power is transferred from gearwheel 1, by the stiffness of the torsion shaft between the planetary gearwheels 3 and 4 (C2), to gearwheel 2. As the shaft between gearwheel 2 and the gearwheels 5 is much stiffer then the intermediate shaft, this stiffness is not taken into account and the inertia's are combined to one inertia: I3.

The hydraulic part is "powered" through transformer TF4 with the modulus equal to the gear ratio between gearwheel 1 and gearwheel 9, the hydraulic pump is modeled as a modulated transformer: MTF1 (rad/sec – m3/sec), then the hydrostatic power is transformed back to mechanical power by the hydraulic motor: TF5 (m3/sec – rad/sec.) and transferred to the planet wheel carrier by TF6 (gear ratio between gearwheel hydraulic motor to planet wheel carrier) and also by the stiffness between the planetary wheels to gearwheel 2. TF2 is the gear ratio between the planet wheel carrier and gearwheel 2. From the closed hydraulic system pipe line, the high pressure side is modeled as 2 stiffnesses (C7 and C8) and one inertia (I5).

To simulate the torque excitations from the pump impeller, the model is excited from a random oscillator which is generating torque pulses on the pump impeller. A centrifugal pump generates in the first place its first order vibration, that is the rev./second times the amount of impeller blades. When there is cavitation in the pump, the excitation is more or less random.

The damping forces are presumed to be proportional to the relative velocities and are also used for stabilizing the simulation process, the purpose of the simulation was to find the resonance frequencies in the system. For the same reason, the friction components are not that accurately modeled.

Measurements and Simulation

The operation of the dredge pump has been measured during dredging. An example is given in figure 4. The recording depicts a torque resonance of about 12 Hz in the intermediate shaft and the hydraulic pressure depicts a resonance of about 2.5 Hz.

The 20-sim model has been used to run numerous simulations. Some results are shown in figure 6 and 7.

Analysis

A reciprocating engine is generating torsional vibrations in the crank shaft and more or less in the shafting of the driven machinery. The most important vibrations in the crankshaft of a four stroke engine are: 1: rpm/120, 2: rpm/60 and 3: rpm/40 respectively called: half order, first order and 1.5 order. The diesel is running at 750 rpm so the induced torsional vibrations are: 6.25, 12.5 and 18.75 Hz. A centrifugal pump is generating vibrations at a frequency of rpm/60 times the amount of impeller blades, this frequency is called the pump's first order. This pump has a four blade impeller so at speed 1 (dredge pump speed = 190 rpm to 240 rpm) the induced first order vibrations are from 190/60 * 4 = 12.67 Hz to 240/60 * 4 = 16 Hz. At speed 2 (dredge pump speed = 300 rpm to 370 rpm) the induced vibrations are from 300/60 * 4 = 20 Hz to 370/60 * 4 = 24.67 Hz.

Analyzing the hydraulic pressure signal from the measurements (figure 4 and 6) reveals that the natural frequencies of the hydraulic system are: 2.77 and 6.18 Hz. The 6.18 Hz

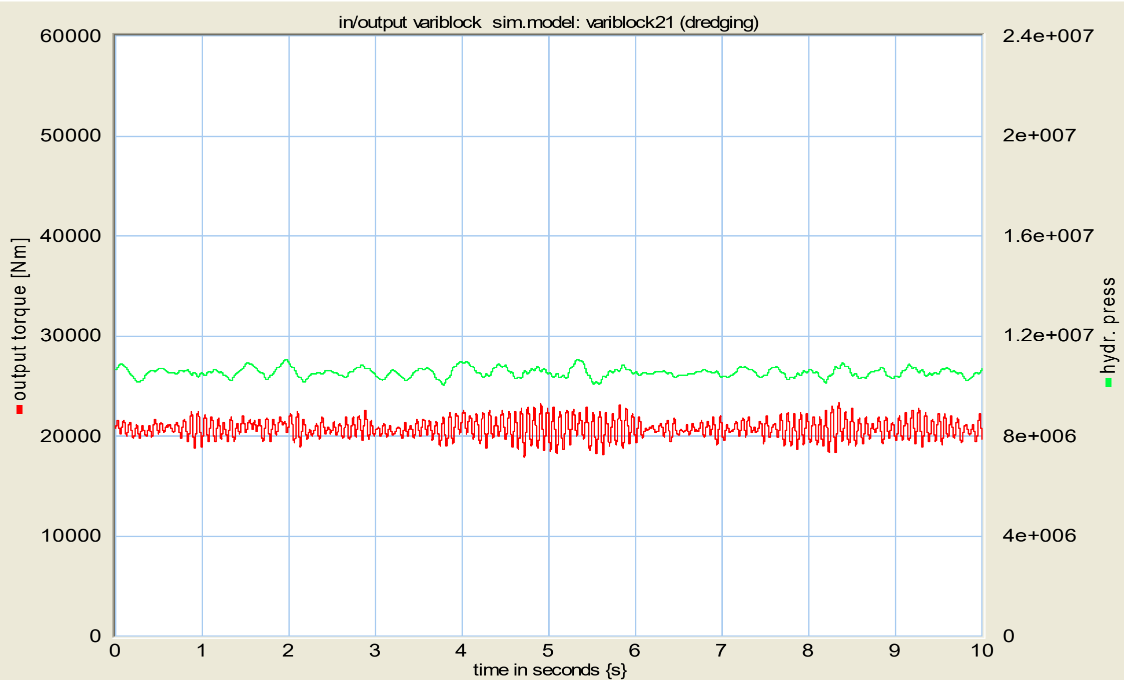

Figure 6: Simulation output, torque in intermediate shaft and hydraulic pressure.

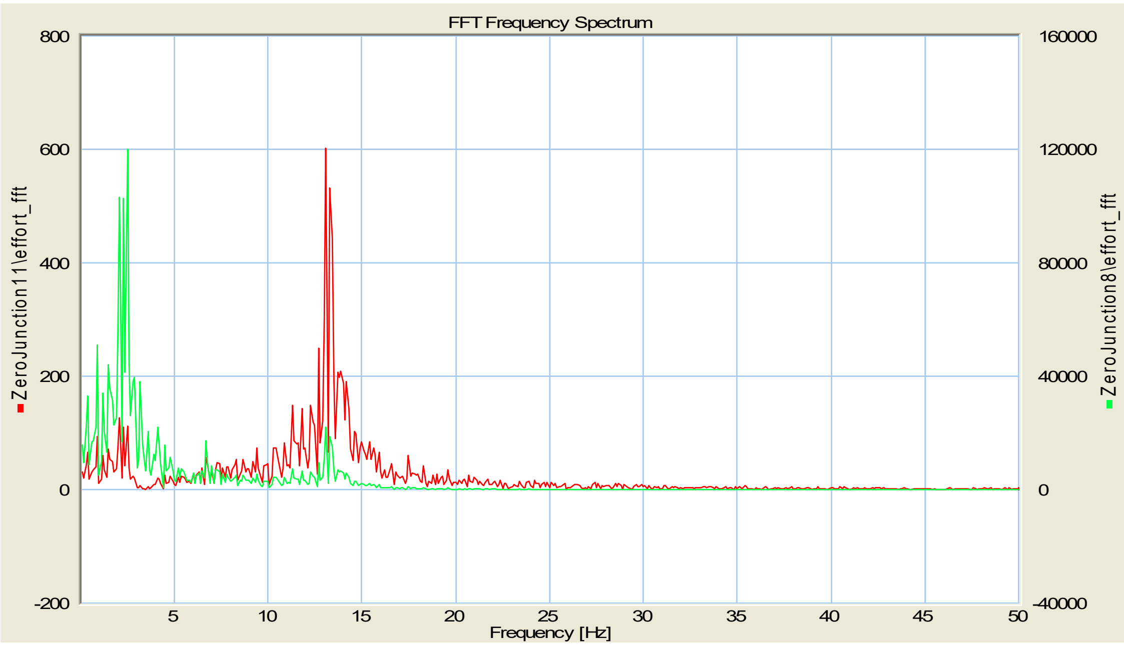

Figure 7: FFT of the simulation output of fig 6.

in the hydraulics is excited or amplified by the half order (6.25 Hz) from the diesel.

FFT analysis of the torque measurement (figure 5 and 7) reveals a frequency of 12.7 Hz this frequency is the first order generated by the pump impeller: pump speed =190 rpm. 190/60 * 4 = 12.7.Hz. The simulation output reveals a resonance of about 2.5 and about 6.7 Hz in the hydraulics. The 6.7 Hz in the simulation output is of small amplitude, because of the simulation model is not excited by 6.25 Hz but it clarifies the amplitude of the 6.18 Hz in the measurements. The torque in the output shaft reveals a natural frequency of about 13.1 Hz.

Conclusions

The traditional modeling approach in engineering is mathematical, but thanks to the advances in computer technology it is now possible for the practical engineer to model systems in a more “user friendly” way. This article demonstrates the power and simplicity of bond graphs in modeling systems. It also reveals the power of 20-sim by using Bondgraphs for model input. The simulation output fits well with the measurements, providing evidence that the simplifications in modeling the system where allowed for this purpose, to determine the natural frequencies of this system. The simulation was done after the design and construction of the gearbox with the hydraulics and the conclusion is that when the simulation was done during the design stage of the system, the hydraulics of the system would have been more optimized. So proper engineering in the design stage is important and the currently available modeling and simulation software makes that possible.

"This fact sheet is an abstract from the paper presented at the Bath Workshop on Power Transmission & Motion Control PTMC 2004.1 - 3 September 2004.at the University of Bath, department of Mechanical Engineering."

Model Based Design

During the use of the Boom Lock, high bending forces can be exerted on the boom. High Wind therefore turned to Controllab to build a model that would allow studying the dynamics of the system. With this dedicated model of the crane, simulations were carried out to investigate the loads under various weather conditions. This type of development is called model based design.

Controller Design

In close collaboration with High Wind, Controllab also developed the control system for the Boom Lock. The control system will run the winches of the Boom Lock and the guiding lines in such a way that the load is transported safe and stable throughout the lift.

Special care was taken with the testing of the Boom Lock control system. The simulation model was coupled to the control system to test all operations in virtual reality first. This technique is called Hardware-In-the- Loop (HIL) simulation and is a special expertise of Controllab. HIL simulation allows to test all kinds of scenarios, even those which in reality could potentially damage the crane. During these test any errors that were found could be solved before the system was implemented on the real crane.

Use

The Boom Lock system has been successfully brought into operation and is now being used to install offshore wind turbines. Meanwhile High Wind requested Controllab to turn the simulation models into a training simulator. Because this simulator is based on sound physical systems models and uses the original control system of the crane, it is very accurate in predicting the real behaviour of the system. It is now used to train crane operators to use the Boom Lock system and test new lifting operations.

Contact

info@20sim.com
+31 (0)85 773 1872