A Simulink Model of an RTG Crane

C. Knight¹, V. Becerra², W. Holderbaum², R. Mayer³

¹Technologies for Sustainable Built Environment Centre
University of Reading, JJ Thompson Building, Whiteknights, Reading, RG6 6AF
c.e.knight@pgr.reading.ac.uk

²School of Systems Engineering
University of Reading, Systems Engineering, Whiteknights, Reading, RG6 6AY
v.m.becerra@reading.ac.uk
w.holderbaum@reading.ac.uk

³CRESS Ltd
Sciotech Office, Department of Engineering, University of Reading, RG6 6AY
rayner@sciotech.demon.co.uk

ABSTRACT

In this paper, the power system and operation of a Rubber Tyred Gantry (RTG) Crane is outlined and the process of creating a suitable mathematical model to allow testing of energy storage is presented. The UK Governments emissions targets combined with the rising cost of fuel are causing industry to look for fuel efficiency technology and strategies. Critically the plant machines cannot be taken off-line for testing due to the cost implications. So a method of evaluating efficiency solutions avoiding this, must be devised. The results show that a SimPowerSystems model is capable of providing a computer test bench fulfilling this need.

Keywords:
RTG Crane; SimPowerSystems; Simulation; Power;

1. INTRODUCTION

The Governments carbon target of 80% carbon reduction by 2050 and 30% by 2025 means that, industries are looking at their operation to find methods of reducing their carbon production. In 2008 2% of the UK’s total GHG (Green House Gas) emissions [1] came from the port operations required to move the 95% of our goods which come in by sea. This amounted to 510 million tonnes moving through the ports in 2010 [2]. Port of Felixstowe (PoF) is the largest container port in the UK, handling more than 2 million containers in that year [3]. In order to move this, ports operate cranes that move the goods from the ships to the lorries and rail network. Two main crane types used at port sites are the Straddle Carrier and Rubber Tyred Gantry (RTG) Crane, this study focuses on the RTG Crane type used at Port of Felixstowe. The crane is a free roaming structure allowing movement across the port; to achieve this they operate using a diesel generator [4]. This entails the combustion of diesel fuel in a fixed speed engine driving a Permanent Magnet Synchronous Machine (PMSM). This system provides the electrical energy needed to run the many motors, drives and auxiliary systems that make up the RTG crane [5]. The crane undergoes a very demanding duty cycles operating in periods of high activity and then long idle times. During the active period the crane undergoes huge stresses both mechanically and electrically, in the drive cycles the current can reach over 600 amps, while in generator cycles the voltage can rise to 750v.
These periods match with lift actions of the hoist and drive on the gantry motors, while the voltage peaks are from the regeneration in the lowering actions and deceleration of the gantry motors. Supplying this consumes large quantities of fuel, with estimates of 22l/hr being used by each crane on site; these cranes operate up to 22 hours a day for over 340 days a year. By harnessing the energy during the generator periods, the energy required during the drive periods can be greatly reduced. This study seeks to develop a computer model of an RTG crane’s electrical and mechanical operation that will allow the trailing of strategies to reduce the fuel consumption of these cranes [6].

2. RTG CRANE

2.1 Generator

As described a diesel generator is used to provide the energy required by the RTG Crane. A diesel engine converts chemical energy into kinetic energy which is then converted into electrical energy in the generator. The rotational speed of the diesel engine shaft coupled with the number of poles in the electrical machine; determine the frequency of the electrical output. The speed of motor rotation is determined using the frequency, rearranging the formula for calculating this allows the calculation of the frequency from the speed applied to the motor shaft.

\[ (1) \]

\[ (2) \]

This means it is essential that the engine maintain constant speed, the power of the engine changes in order to meet demand from the system. The fuel consumption of a diesel engine is directly related to the power output of the engine, so it would be desirable to avoid as much of these power increases as possible. This can be done in two ways, either lowering the demand from the system or by using a device that reduces the system demand on the generator.

2.2 Motors

The motors are the main load on the system, the crane has seven motors which provide all drive actions for the crane. A single motor, rated 185kW provides the hoist action, while two motors rated 18.5kW give the trolley action. These three motors allow the crane lateral and vertical movement so the spreader can be positioned above containers and move them to lorries which stop inside the footprint of the crane as shown in Figure 1.

Figure 1: RTG Crane
The final four motors, rated at 45kW each provide the drive to the crane structure allowing it to move around the port site. At peak this can mean the four motors drawing as much power as the hoist. All these motors are squirrel cage induction machines, a form of AC machine requiring no magnets.

The machines have a set of coils on the stator and rotor, by the proper activation of the coils on the stator and rotating magnetic wave is established. Through the laws of electromagnetism a current is induced in the coils of the rotor, once this happens the rotor begins to experience a force. By modulating the activation of the stator coils the rotor can be made to rotate at various speeds, up to a maximum determined by the physical characteristics of the machine. When the rotor speed is below that of the rotating wave the machine is said to be motoring and will draw a current to maintain motion when loads are added. When the rotor speed is above that of the rotating wave then the machine is said to be generating, under this condition the motor will output current. Looking at the duty cycles the motors of the crane go through both these stages, the large current spikes show when the machines are motoring and the raised voltage shows when the motors are generating, shown in Figure 2.

![Figure 2: Power Flow on RTG crane during typical operation.](image)

2.3 Operation

The crane is operated in both day and night conditions so the auxiliary systems of the crane require significant levels of power, ranging from 20-40kW. This can be a significant constant demand on the generator. The crane operates according to the logistics of the port site on which it is being used, at PoF the cranes are used to transfer containers into and out of holding areas. The containers are lowered from the ships onto port trucks which take them to the stacks, an RTG will then lift the container onto the stack, when it is required the RTG will lower it onto a lorry. The container may end up at the bottom of a stack leading to others having to be moved before it can be accessed this changes the duty cycle quite heavily. The crane also undergoes long idle periods between these lift cycles. The trace in Figure 2 shows a typical period of activity when the crane is lifting a container, during the raise period the corresponding current increase can be seen and during lowering the regeneration can be seen through increased voltage. The energy that is generated by the motors cannot go back into the generator, to remove this energy which could damage components dump resistors are used.
These devices are engaged when the voltage rises and all regenerated energy is then wasted as heat into the atmosphere. It is this energy we hope to harness to reduce the demand on the diesel engine and its fuel consumption.

3. COMPUTER MODELLING

Using the RTG crane for design and development is a costly and time consuming affair. Due to the nature of the operations the crane cannot be taken offline without significant cost and logistic implications. This means that when a system is trialled to improve efficiency the crane must be put immediately back into operation, should a fault occur the trail system will be disconnected. So any system that aims to improve the use of energy has to be designed, developed and debugged beforehand. Computer modelling allows us to run trials like this without having to affect the operation of the actual plant the system is designed for. By developing computer models of the RTG crane it is possible to simulate both the electrical and mechanical actions of the crane. These simulations can be run at anytime and at no cost to the operator of the crane, they allow for rapid prototyping of efficiency solutions and give a clear indication of their potential effects on the actual crane.

4. COMPUTER MODEL

The computer model was developed in the Matlab/Simulink environment, with the help of the SimPowerSystems toolbox [7]. Both the electrical and mechanical systems of the crane must be modelled to ensure the correct functionality is included in the model. The electrical system will provides the power during motoring stages but it is the mechanical properties of the system that will determine the generation in the system. The major components of the crane are the diesel engine and generator, the seven induction motors and the dump resistors. These machines were implemented using pre-existing ‘blocks’ within SimPowerSystems, the induction machines are derived from the following electrical model.

\[
\begin{align*}
R_s \cdot \omega \cdot d_s &+ L_s \cdot i'_{ds} \\
V_{qs} &- i'_{qs} \\
L_m \cdot i'_{qs} &- R_r \cdot i'_{dr} \\
V_{qs} &- V_{ds} \\
L_m \cdot i'_{qs} &- R_r \cdot \omega \cdot i'_{dr} \\
V_{ds} &- V_{dr}
\end{align*}
\]

Figure 3: Electrical model of induction machines.

where, \(V_{qs}, V_{ds}, I_{ds}, I_{qs}\) are s, d, q axis stator voltage and current, \(R_s, L_s\) is the stator resistance and leakage inductance, \(L_m\) mutual inductance, \(V_{qs}\) the referred rotor voltage, \(\omega, \omega_r\) are the rotating field angular velocity and rotor velocity respectively. The mechanical model is derived from the following equations:

\[
\begin{align*}
\frac{\partial \phi_{ds}}{\partial t} &= \omega \cdot \phi_{qs} \\
\frac{\partial \phi_{qs}}{\partial t} &= -\omega \cdot \phi_{ds}
\end{align*}
\]
where,
The results from the first test set are shown in Figure 5. The models current and voltage profile, shown in the first two plots, follows that of the actual crane, the periods of regeneration show voltage levels peaking around 750V, within 1% of desired value. The hoist and gantry motor effort is shown in the 3rd and 4th plot of the results, the correlation with the current and voltage can be seen clearly. The period of lifting shows a voltage drop of a similar order to the test data. The simulations do not show exactly the same response as the crane to the duty cycle. This is because the simulation data was derived from traces showing the power system output, Figure 2, not from raw data from the crane. The second set of data was recorded on the RTG Crane as it went through the duty cycle depicted in Figure 8(a). Initially the first container has to be moved resulting in the same voltage and current profile as that in the first test. In this case the crane then has to return to the stack and move a second container.
From the test data from the crane a similar cycle of the voltage and current occurs, the difference caused by differences in the container weights. In the real system the energy is again wasted as heat in the dump resistors.

The current and voltage profile from the model for the second validation set show the same level of accuracy as the previous test. This combined with the results from the 3rd scenario, Figure 7, demonstrate that the system is general, capable of handling general conditions experienced by the crane rather than a specific set. The results are shown in Figure 6 and demonstrate clearly the fluctuating nature of the power system of the RTG crane. By harvesting the regenerative energy it is hoped that the power system may be ‘smoothed’.

The final test set represents the most intensive duty cycle the RTG Cranes go through, it is depicted in Figure 8(b). The energy regenerated in this cycle is again all lost in the dump resistor. These last two scenarios demonstrate where energy storage would be useful. In the final results the model replicates the cranes most taxing duty cycle, as with the previous results the variable nature of the power system can be seen.
In this situation the ‘smoothing’ affect of an energy store can improve the response of the system, reduce fuel usage and reduce the wear on the component parts of the crane. The simulation results agree with the validation data and a very good accuracy is achieved.

7. CONCLUSION

A system for modelling of electrical power systems was presented and used to devise a model representative of a RTG Cranes power system. The computer model was built using the SimPowerSystems toolbox in the Simulink environment, the set up and operation of the model have been explained as well as the basis for the important components. Validation test data has been presented and explained, testing the model against typical duty cycles of a real RTG Crane currently in use at a port facility. The results have been shown as comparable to a real RTG Crane’s response in terms of both current and voltage. The mechanical action that accompanies the variation in the power system has been shown and explained. This gives confidence for the next stage of development of the model.

In the future the model is to be run alongside a 3D animation of an RTG Crane, this will allow the testing of the model against the actions taken by drivers in real life. It will also be a useful visual aid to confirm how the model is working to those unfamiliar with interpreting its output. The model will be fitted with a block to represent an energy storage unit and a control strategy designed to optimise its use against realistic duty cycles like those of the validation set used here. In order to confirm these results an experimental rig is being constructed that will enable any benefits shown by the model to be quantified using various industrial components, including electric motors, drives and flywheels.

REFERENCES


