STATIC & DYNAMIC MODELING OF ESP WELLBORE APPLICATIONS

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Introduction:

With the evolution of design and evaluation software for Electric Submersible Pump (ESP) systems over the last 25+ years, most of the development and emphasis has been on ESP design, or sizing. All of the ESP manufacturers have, at one time or another, been involved in internal development of ESP sizing software and there have also been several third party companies who have developed similar programs.

This paper will introduce the expansion of a design and sizing software program into a tool, which can be utilized for time variable modeling and simulation. AutographPC® Software version 4.0 is the latest in the third generation of ESP design software from Centrilift. With this release, the design capability has been expanded to include an ESP system simulator. This **simulator adds** the **time** variable to the sizing, in such a way that the user can see the dynamics of the well operation in conjunction with the ESP operating point.

Static ESP Modeling:

Static modeling techniques have evolved over the years from simplified manual calculations to elaborate computer software programs. Manual calculations are still used today in wellbore applications where the fluid is mostly water and there are no other fluids or wellbore conditions that add serious complication to the process. If the conditions become more complicated, then automated or computerized design systems are recommended. This is especially true in dealing with gassy or viscous fluids, and/or variable speed drive applications.

The techniques utilized by most of the software are based on a well established process, which is detailed in API Recommended Practice 11 **S4,** "Sizing and Selection of Electric Submersible Pumps". The logic for the basic ESP design process is shown in Figure 1. Typically, an ESP design is started by entering well data such as oil gravity, water cut, productivity index and static pressure. The description of the well bore is also done at this stage of the design. This establishes the static or non-flowing, non-pumping condition for a particular wellbore.

Once the productivity of the well is fully established and a desired flowrate is specified, the required downhole pump discharge pressure can be calculated. Then, the required ESP equipment can be sized starting with the pump, where the goal is to determine the number of stages based on the pressure or Total Dynamic Head (TDH) required. Once the pump has been established, the required horsepower (HP) can be calculated and the motor selected. The cable and controller are then sized in accordance with the motor requirements. Regardless of whether this is done manually or with the help of computer software, it is still a "bottom-to-top" type of approach.

When the design process is completed, it fully describes two operational points for the ESP system, Figure 2. The first is for the static, non-flowing or non-pumping wellbore condition. The second is for the stable, flowing or pumping condition.

If the designer then wants to check the operation of this particular set of equipment with varying wellbore conditions, the calculations can be redone or the computer program rerun for the changed conditions. This is somewhat harder to do because any change in wellbore conditions (like PI, water cut, desired flow etc...) would directly affect the operating point of the ESP. The equipment performance curves (polynomials) and multiphase-flow correlations are not designed to work in 'reverse'. This can only be mathematically solved using an iterative approach making it virtually impossible for hand calculations. AutographPC® Software has several built-in tools that can do the necessary iterations from one static condition to another static condition. This last approach still cannot give you the complete picture because you are just computing operating parameters at two different static (or 'stable') conditions, Figure 3. It does not describe the dynamic wellbore conditions that the equipment moves through, between these points, as a function of time, Figure 4.

Dynamic Modeling:

AutographPC® Software's ***Simulator*** feature is the first attempt in the industry to resolve the dilemma of "what happens with the operation of the ESP as a function of time when well bore conditions or operational parameters change?' This is done in a smooth and integrated way with the process tied to the original design. It also eliminates the need to re-enter information about the wellbore or the selected equipment. When adding the time variable, there are additional measurable effects including acceleration, inertia and capacitance that would normally be ignored in a steady state-type of analysis.

The basic ESP simulator sequence is shown in Figure 5. It utilizes the same design segments as the basic ESP process, just in a different order. With the Simulator, once a time control is activated, the process flows through the Controller, Cable, and Motor sections to recalculate the step change in their output parameters. The process then flows on to the Pump section to calculate the change in the intake and discharge parameters and finally the output flow of the pump. As a final step on the loop, it is linked back to the time control for another step change.

Basic Features:

The Simulator screen has six (6) different sections, which allow either control of the ESP operation or monitored parameter displays. **A** description of the function of each section follows.

1. Control Section
   - Controls power to the simulated ESP unit.
   - Includes start, pause/resume, and stop buttons.
   - Controls the production tubing valve from 0% to 100% open.

2. Wellbore Graphics Section
   - Simple wellbore schematic.
   - Moving tubing and annulus fluid levels.

3. Simulation Time Control Section
   - Controls the speed of the simulation.
   - Run at real time or use multiplier to speed it up.
   - Monitors and displays pump-up time.

4. Gauges Section
   - Displays seven (7) bar gauges which can show and monitor parameters from 26 different, selectable items.
   - Each has auto or manually settable hi-lo alarms and total gauge ranges.
   - Typical parameters include: Flowrate (perfs, annulus, pump), Pressure (tubing, pump intake and discharge), Temperature (pump rise, motor), TDH, HP, RPM, Motor electricals, etc.

5. Logger Section
   - **A** data logger function with plotting capabilities for the seven parameters displayed in the Gauges Section.
   - Some graphing reformatting options.
   - Export via clipboard.

6. Event Handler Section
   - Contains over twenty (20) event parameters, which can be selected and their original settings modified. Includes event parameters such as:
     - Fluid conditions – GOR, s.g., P_r, P_{tbg}, PI, etc.
     - ESP conditions – Frequency, VSD volts, pump curve modifiers, rotation, wear, etc.
     - Completion conditions – packer, wellhead valve, tubing leak, etc.

Simulator Uses

There are three major areas where the Simulator can be utilized. The first is to model the dynamics between the static starting condition and the stabilized end design condition. The second involves the effect of a changed or changing parameter on the ESP operation and wellbore conditions. And third, the ability to model changes to re-enact ESP operational problems or failures. These situations are shown in Figure ***6*****.**

1. Model ESP operation under fixed wellbore conditions (Start-up, running, shut-down, etc):

    The ***Simulator*** can be used as an excellent training tool to show, in a graphical and intuitive form, the interaction between the operation of an ESP system and the fluid levels and pressures in the well. It calculates and displays this from startup, to steady state, and through shutdown. There are also min/max markers in the graphical gauges that give an indication of where the unit **is** operating relative to any limits. In the case of the pump flow rate, they indicate the manufacturer's recommended range of operation. If the design contains a Variable Speed Drive (VSD) you can see the effects as you change frequency. It is interesting to note how the dynamic model exposes sometimes unexpected changes of the pump's operating point as you change certain conditions.

    Another interesting result of a simulation is to get an indication of how long an ESP can take to stabilize after a change is made. Figures 7 and **8** show data plots of information taken during a simulation. Both figures are for the same simulation. Figure 7 is a plot of Pump Discharge Flowrate (Qpmp), Flow from the perfs (Qperfs), and Pump Intake Pressure (Pip) versus time. Figure **8** indicates Pump RPM (RPM), Motor Temperature (MTemp), and Motor Amperage (MAmps) versus time. The simulation put the ESP equipment through a typical start-up, operation until wellbore stabilization, a variable speed controller frequency increase, and shutdown.

2. Model ESP under varying wellbore parameters:
    Most interesting is the capability to change wellbore parameters to see the immediate effect over other parameters. For example: after reaching a stable operating condition, change the Productivity Index (PI) and see what effect it has on Pump Intake Pressure (Pip) and total flowrate. If the well is being monitored with a downhole pressure sensor, this could be used as a mechanism to help identify what that PI ***really*** is by simply changing it in the Simulator until the PIP matches.
    As a well ages, you can model the effects of a relatively quick initial drop in PI, for the first few days of production and later the Static Pressure (Pr) as the well starts declining. Additionally, you could model rising water cut and declining GOR. The ***Simulator*** can be used to see what effect any of these changes have over the final production and operating point of the ESP.

3. Use to re-enact failure modes

The ***Simulator*** can help to model well-related operational problems and other types of 'short term' failures. Examples of operational problems include wear from abrasives in the production fluid, plugging from scales or asphaltines, and changes in the fluid viscosity or free gas content. When an ESP is applied in an abrasive environment, with time, any given pump will show some wear. This wear is translated as a drop in pump performance and will affect both the pump's flowrate capacity and the head produced. A wear variable can be utilized in the Simulator to model and estimate the change in ESP performance. Similarly, variables can be modified to model pump plugging from scale or asphaltine.

Additionally, short term failure modes that can be modeled include items such as: broken pump shafts, closed wellhead valves, and tubing leaks.

Conclusion

The Simulator is the next step in the advancement of ESP design and application software, which has been developed as a tool to aid the user of ESP systems. It serves as both a training tool to model the dynamic operation of an ESP system in a specific application and an evaluation tool to better understand why an ESP behaved in a particular manner to specific wellbore or outside induced parameters. **As** with any tool, its true value to the user will become known as it is applied to help understand and solve the issues which affect every ESP application.

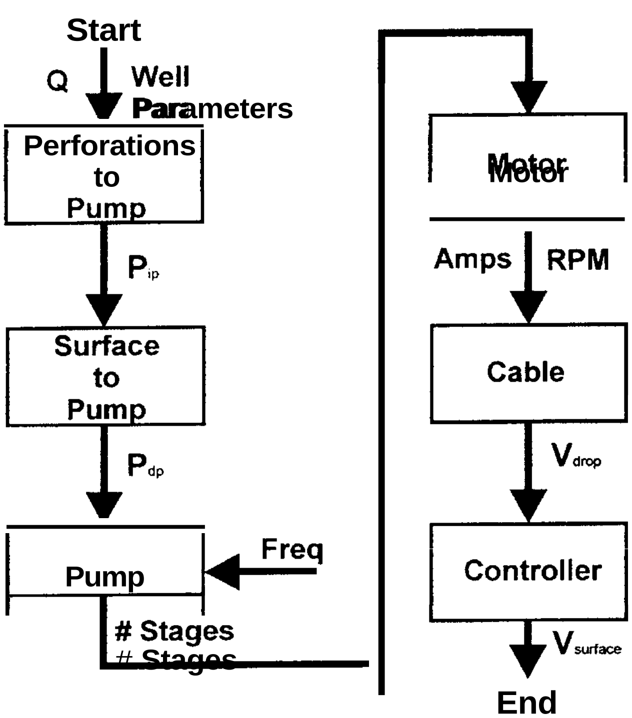

Figure 1 - Basic ESP Design Sequence

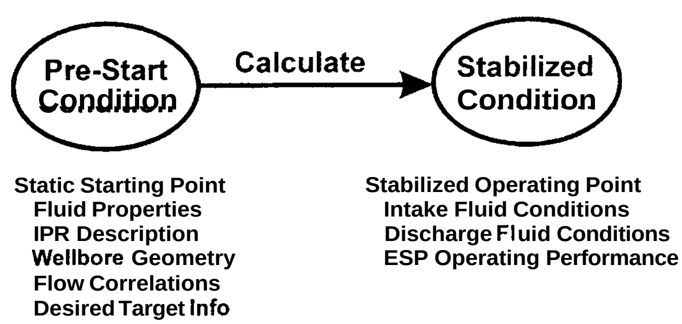

Figure 2

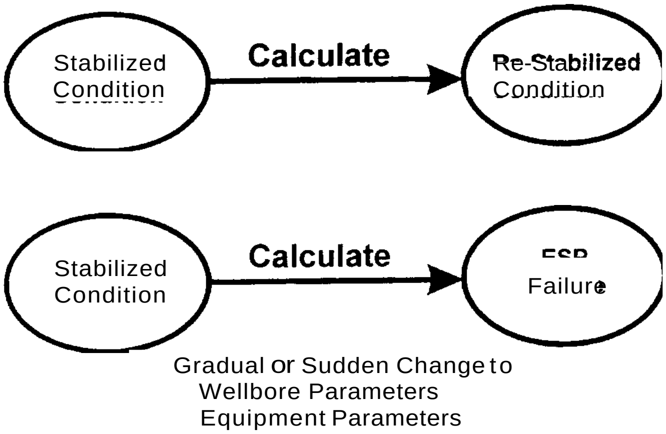

Figure 3

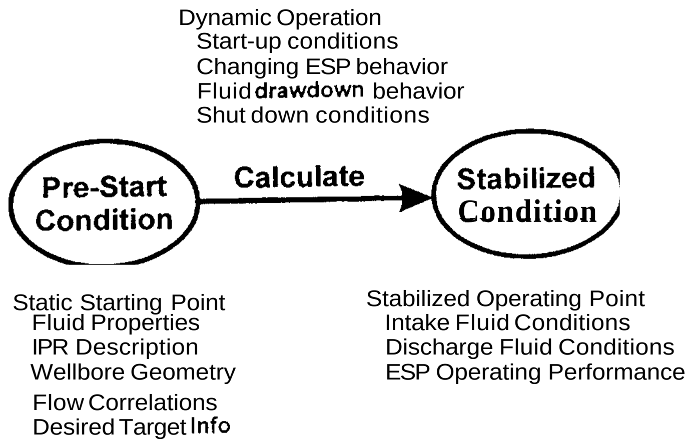

Figure 4

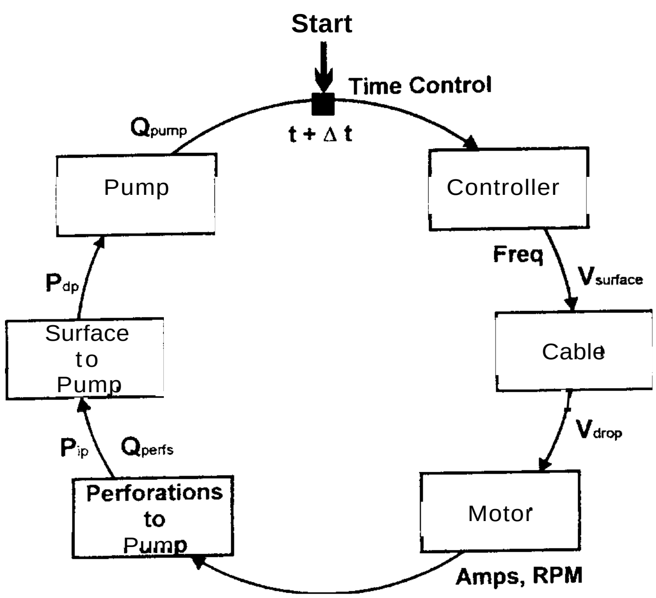

Figure 5 - Basic ESP Simulator Sequence

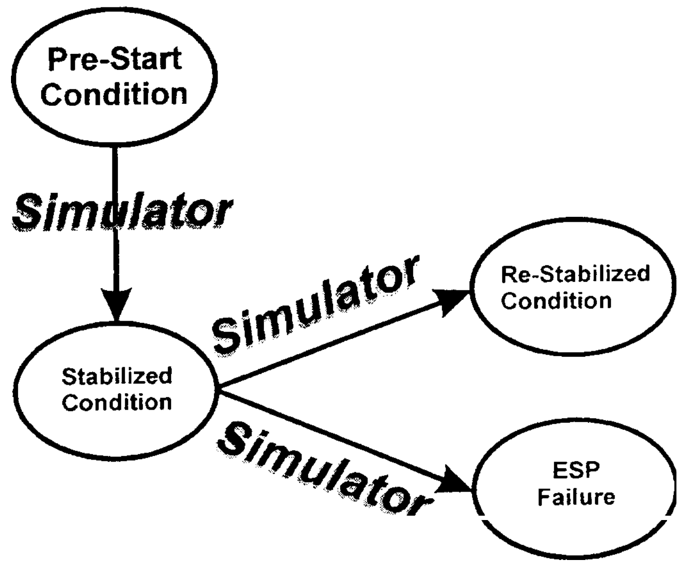

Figure 6

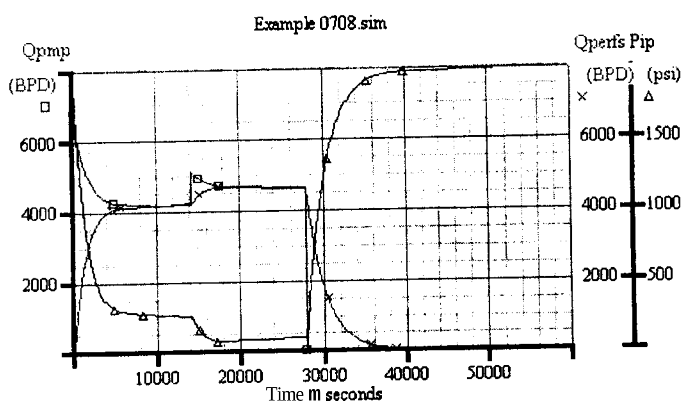

Figure 7

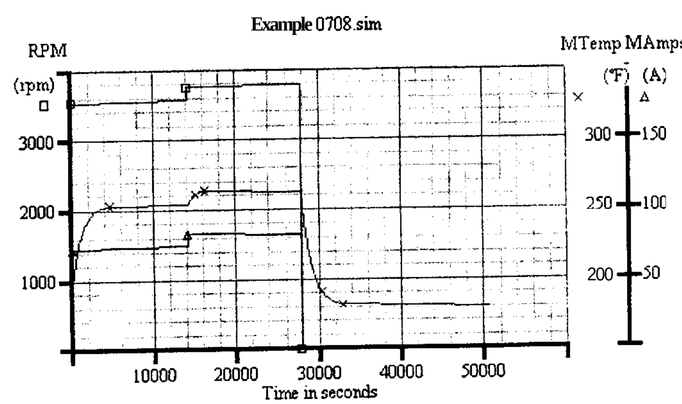

Figure 8