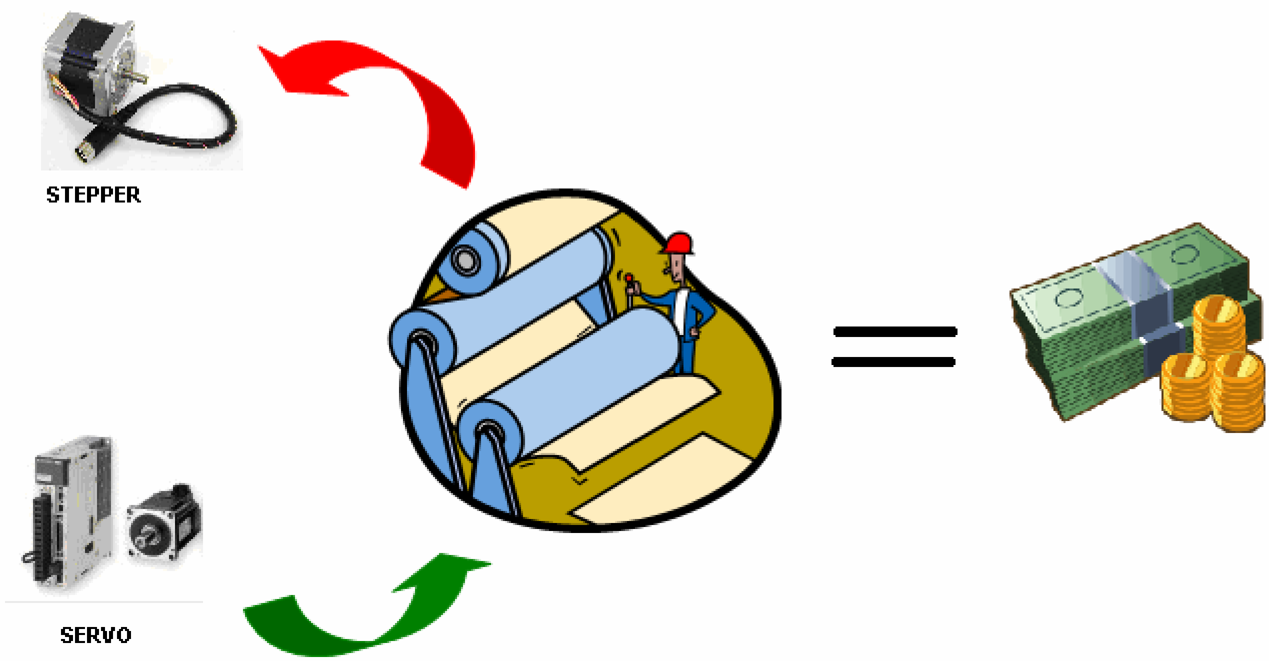
ELIMINATING THE PAIN OF STEPPER-TO-SERVO CONVERSION:

Productivity and efficiency enhancement made possible by easy-to-tune advanced servo systems



Abstract:

Today's highly dynamic marketplace requires machine manufacturers to be constantly on their toes. Innovation, flexibility and user friendliness are constantly being emphasized by customers. Machine manufacturers frequently have to come up with features and attributes in their machines that help the customer become more efficient. Efficiency is related to easy startup, high throughput and less downtime. Stiff competition also calls for price effective strategies to be adopted by machine builders as well. Therefore, competition and customer demands are the driving forces for better products and innovation in the field of automation.

With the above in mind, this paper describes how significant improvements in technology have helped Yaskawa Electric manufacture the most advanced line of servo systems. This will help both OEMS and End Users reap the benefits of innovation through state of the art, user friendly and competitively priced servo systems that are industry leaders in reliability and performance.

Situation:

To put things in perspective, the goal at hand is to improve machine throughput and performance by switching from stepper technology into the realm of servo technology. Although both technologies have their advantages, switching over to servos may prove to be the wiser choice over time due to the increased productivity, reliability and savings.

The initial costs of making the switch may seem overwhelming at first, but one must look towards the rewards of the long-term payout. Spending a little extra money now could ultimately save a lot later. In order to justify the conversion from steppers to servos, three issues must be examined. These concern the topics of torque and speed requirements, cost and the ease of tuning and start-up. All of these things will be examined further.

Issues:

1. **Torque and Speed Requirements**: Can the switch be made without large changes to the machine design, as time and money are of valued importance? The switch should dimensionally be acceptable within the current machine designs. Also, the servo system should be able to meet or exceed the high standards demanded by productivity and flexibility specifications. The servos that will replace the steppers will have to operate at both high torques and high speeds. In short, the servos will have to pack the powerful punch despite coming in a small package.

2. **Cost**: Is it cost effective to replace steppers on the machines with servo motors? On switching over to servos, how much of a price rise difference are they going to see and is it acceptable? Can you convince customers of the advantages of such a price rise?

3. **Tuning and Ease of Startup**: How easy is it to tune and start up a servo system? Since stepper systems do not require tuning, commissioning a traditional servo system often requires a new set of skills. The general opinion of machine builders and customers is that servos are difficult to tune to specifications, especially when there is mechanical compliance, large inertial loads, or when fast settling time and high holding torque are needed. An ideal servo system would reduce or eliminate the tuning efforts required of machine builders.

Solution:

1. **Torque and Speed Requirements**: Servo systems are well proven in providing high torques at wider speed ranges, and Yaskawa Electric's latest Sigma-5 series underscores that fact. The Sigma-5 series is the newest and most powerful generation of Yaskawa's reliable Sigma series servo products. The new design aided by the latest technology has made it compact and efficient.
   - The number of parts in the Sigma-5 is 30% less than its predecessor, improving reliability.
   - Improved feedback design has doubled the motor rating for shock and vibration.
   - Cutting-edge stator and winding designs have reduced the size of the motor for given power levels.

Dimensions of a stepper motor and a similarly sized Sigma-5 servo motor are shown in Figure 1. The size of the stepper is 83 x 83 x 126 mm and it weighs 3.8 kgs. The Sigma-5 servo is 80 x 80 x 115 mm and weighs 2.7 kgs.

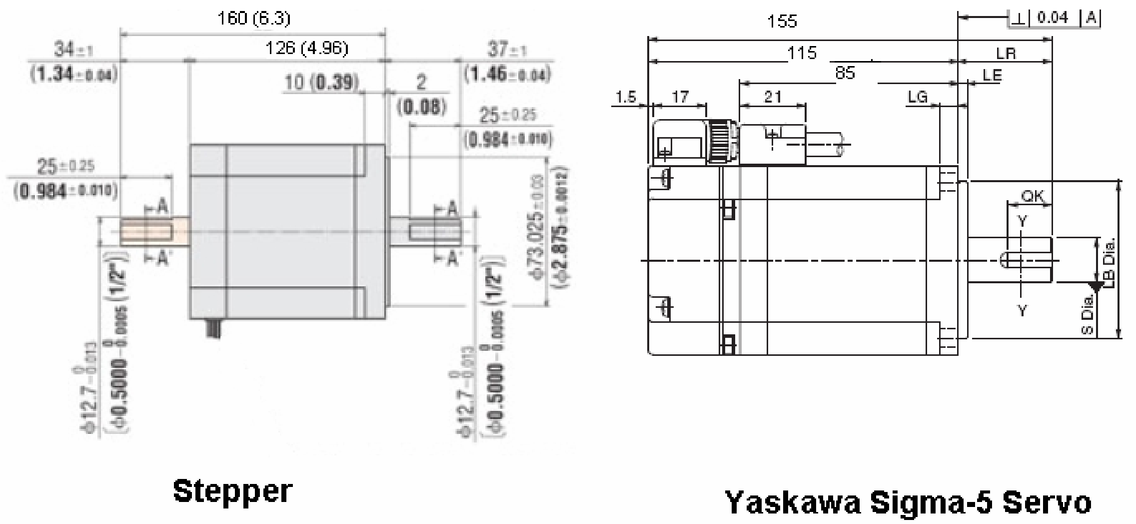


Figure 1: Comparison of motor dimensions between a stepper and a servo of comparable size.

A power density comparison between these two motors is shown in Figure 2. The illustrations are comparative plots of the speed vs. torque curves. Please note that the stepper plot has speed on the x axis and torque on the y axis. The servo plot has torque on the x axis and speed on the y axis. The comparison clearly shows that the servo provides a wide torque range at high speeds, despite being in a smaller package. The dark border on the servo plot in Figure 2 is the instantaneous torque curve. The light colored curve on the servo plot denotes the continuous torque provided by the motor (available infinitely). This clearly displays the ability of a servo system to deliver high torques at speeds up to 6000 rpm. Such speeds are not even achievable using steppers, which top out at approximately 2000 rpm, bleeding available torque along the way. Such a servo system with high speeds will help increase the manufacturing productivity and throughput. The wide torque range available will help the machine become flexible enough to handle products which require different torques.

An often overlooked issue when sizing step motors is allowing for enough *torque margin*. Step motor systems are open-loop by nature. If the torque requirement exceeds what the system can deliver, the motor will stop turning (stall). Without position feedback, the controller will incorrectly assume the motor has reached the desired position. On many machines, motor stall conditions and position loss can lead to increased scrap rates, increased downtime and reduced productivity. At worst, these conditions could lead to physical interferences and machine damage. Any of these consequences increases the overall cost of ownership of the stepper system. To guard against this, engineers typically must add 50% torque margin to worst case move conditions when selecting a step motor. This can lead to a much larger motor than necessary.

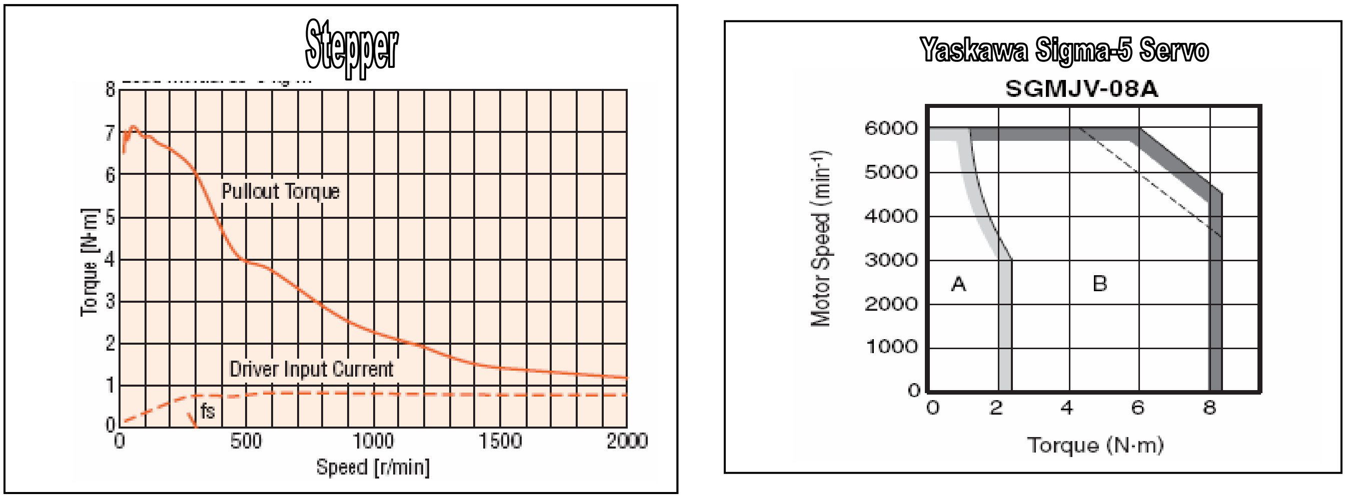


Figure 2: Comparison of torque speed curves between a stepper and a servo of comparable size.

2. **Cost:** A stepper motor is cheaper than a servo motor if a direct cost comparison is made. However, the investment made on a servo system can pay off in the long run. As an industry leader in providing quality servo products, Yaskawa servos have a very high Mean Time Between Failure (MTBF). The 20-bit encoder installed on the Sigma-5 motor gives the user a resolution of more than one million counts in every revolution. This gives a clear indication of how accurately positioning can be carried out in a closed loop format. Such high resolution makes for more accurate positioning, thus improving production quality.

   The Sigma-5 can also operate at higher speeds and at higher torques, which help in speeding up process time and increasing plant throughput. Over time, the higher cost of a servo system is paid for by increased productivity, and the total cost of ownership is reduced.

3. **Easy Startup and Tuning**: Tuning a servo is thought of as an “art” by many. Tuning a servo system that is installed on a machine requires adjusting feedback gains of the servo system to satisfy the output performance specifications of the user. The specifications could be limits on overshoot, settling time or position error. Tuning is made difficult if the load inertia is much higher than the inertia of the motor being used to drive the load. Once the inertias are calculated, the output specifications can be met by adjusting feedback gains using equations that model the physical and electrical components of the machine. This is the most complex, time consuming and tiring part of tuning, and is the reason why most people shy away from this process.

   Yaskawa Sigma-5 tuning techniques take the complexities away from the user. The equations and optimization routines are done internally, taking the math and related complexities away from the user.

There are three different ways servo tuning can be accomplished with the Sigma-5 system:

1. Adaptive Tuning-less Function
2. Autotuning

3. One Parameter Tuning

Tuningless Function:

The tuning-less functionality, enabled as a default, allows for simple setup and provides consistent performance *without having to adjust any feedback gains.* This can be used for general-purpose axes not requiring very specific responses. The tuning-less function has adaptive features that continually adjust to provide satisfactory performance even if the load changes by 20 times. This adaptation is performed by varying the torque during acceleration and deceleration, helping first-time users with no background in tuning at all. Even experts can appreciate that a system can be commissioned *without tuning intervention* by the technician.

Autotuning and Advanced Autotuning:

Autotuning and advanced autotuning are used when very strict specifications are laid out on the performance of the servo. This level of tuning is best carried out using a free software tool. Yaskawa Electric has introduced an advanced software tool that helps in setting up, tuning and monitoring servopack parameters. This tool, SigmaWin+, is armed with several enhanced features that save time for controls engineers. Auto-tuning is just one of the many configuration wizards highlighted in this software tool that helps guide users through the various steps of setting up a servo system.

This tool is easy to navigate and guides the user to provide data about the application through a series of simple questions. A highlight of the tool is an automated moment of inertia calculating procedure a shown in Figure 3.

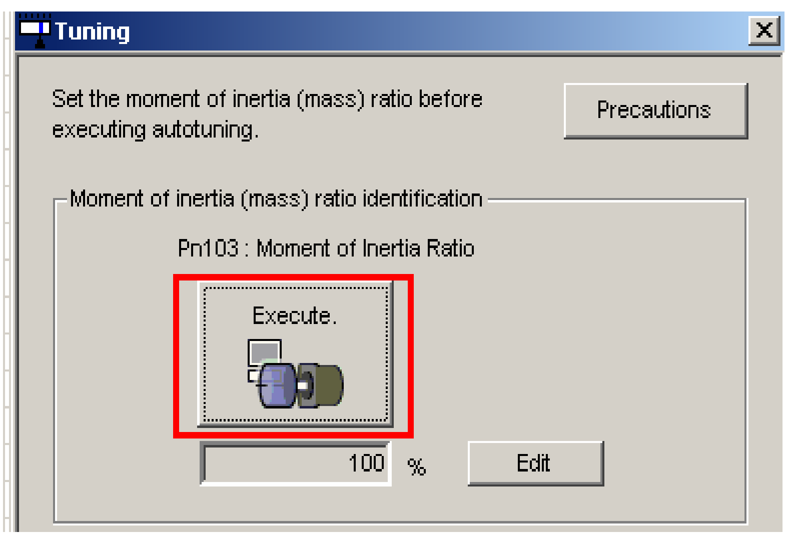


Figure 3: Inertia estimation

Advanced system identification techniques are employed in this part of the software. Once the moment of inertia calculator is turned on, automated test commands excite all modes of the system that are used for physical movement. The system response is then captured and analyzed to estimate the moment of inertia of the attached load. The accuracy of the estimation result is astounding. Figure 4 documents a test example where a known 10:1 inertia load was used, the automated inertia identification function estimated the inertia ratio to be 9.66:1.

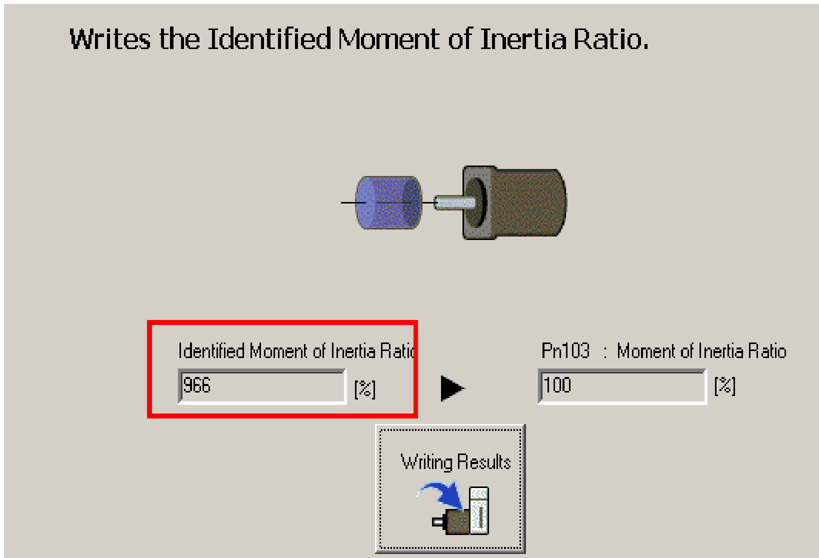


Figure 4: Inertia estimation results

The autotuning feature next guides the user through a series of steps where information is collected about the system type and application mode.

Autotuning begins with user selection of operation mode and system model as shown in Figure 5. The Sigma-5 will use different algorithms depending upon the mechanical model chosen. Based on the mode (position, velocity or torque), unique reference signals are used to automatically tune the system. The reference signals are used to drive the servo and the feedback is monitored to gauge the level of gain optimization. Various sets of reference signals are used to fully tune the system. Autotuning takes the system through various steps such as oscillation level measurement, and adapts feedback gains in real time such that the best possible responses are obtained from the system. A snapshot at the end of a two-minute autotuning process is shown in Figure 6

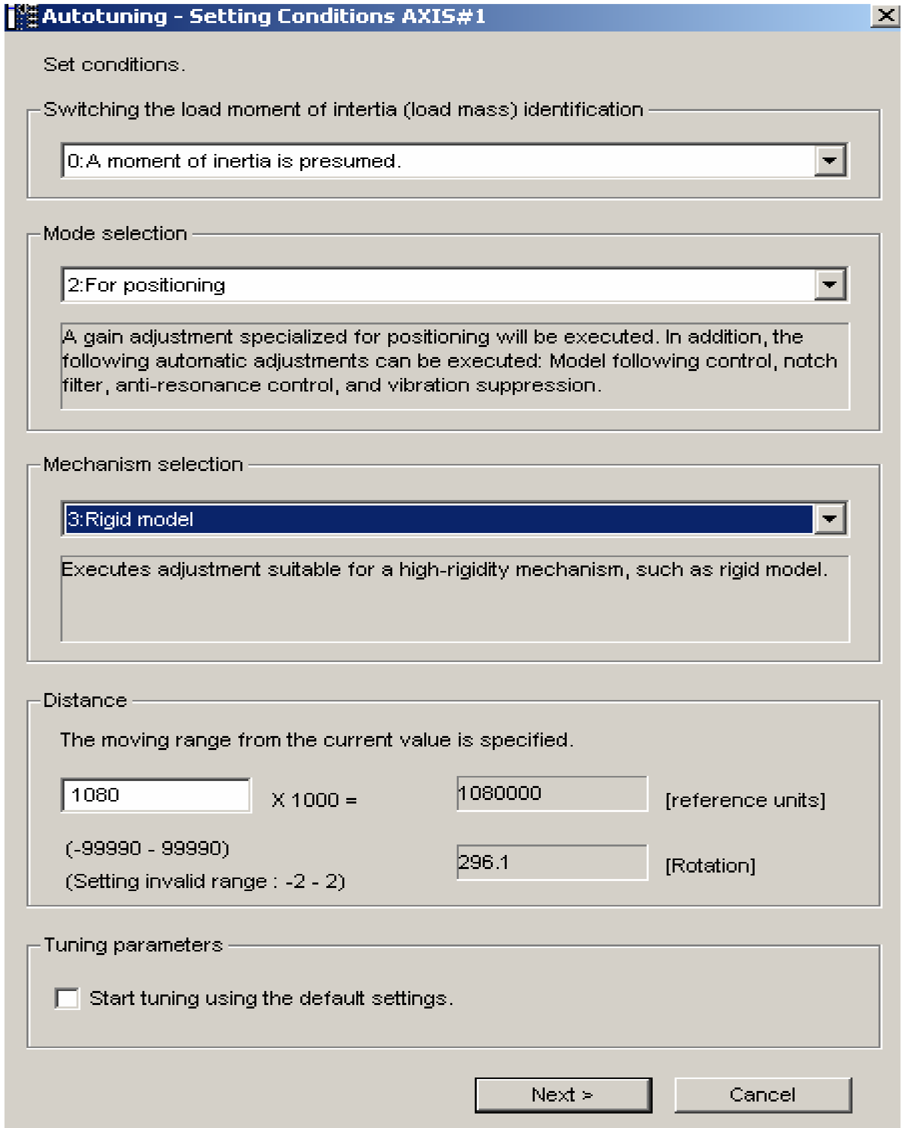


Figure 5: Interactive autotuning process

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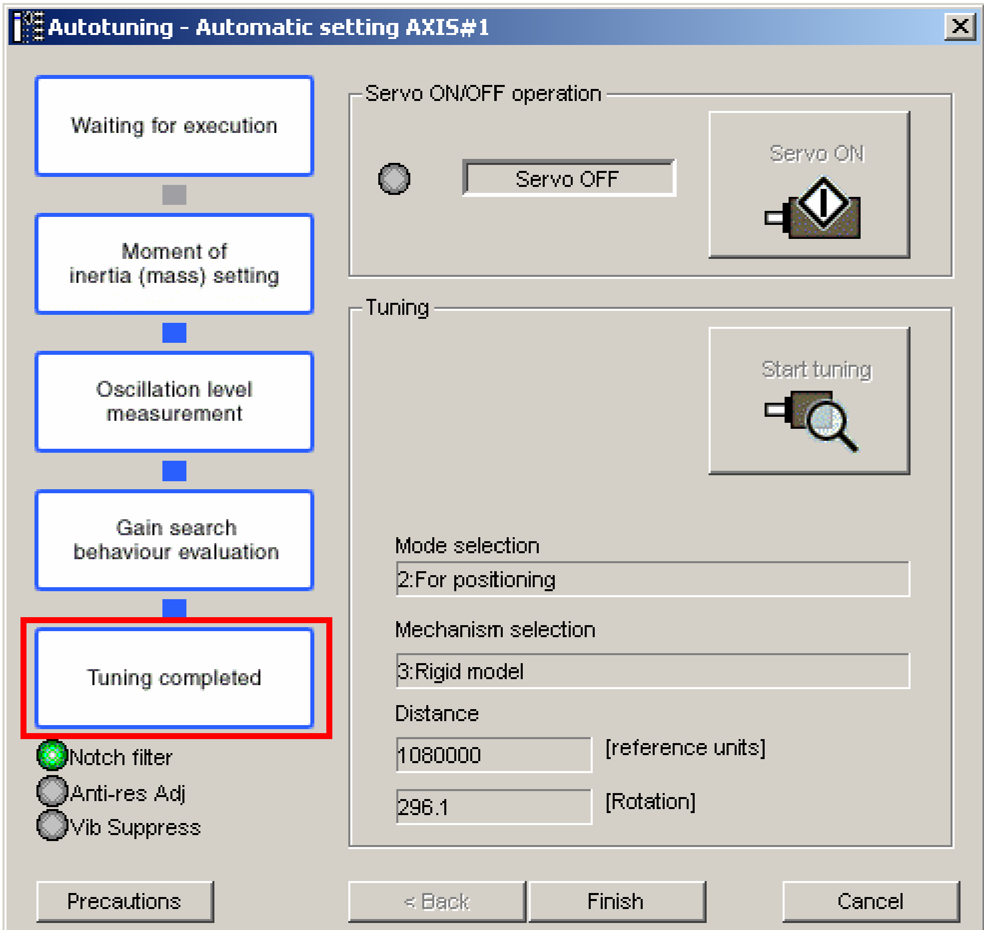

Figure 6: Completion of autotuning

Advanced autotuning can also be used to place filters (torque reference and notch filter), for friction compensation, anti resonance control and vibration suppression. Advanced autotuning can also be accomplished with an upper level host controller. The vibration suppression function, when enabled, detects and suppresses vibration in the 0-100 Hz range commonly generated during the execution of very fast positioning moves. This reduces settling time greatly, while preserving accurate positioning.

Figures 7-9 compare the resulting performance of an untuned system, a system employing the tuning-less function and a system tuned by execution of the autotuning procedure.

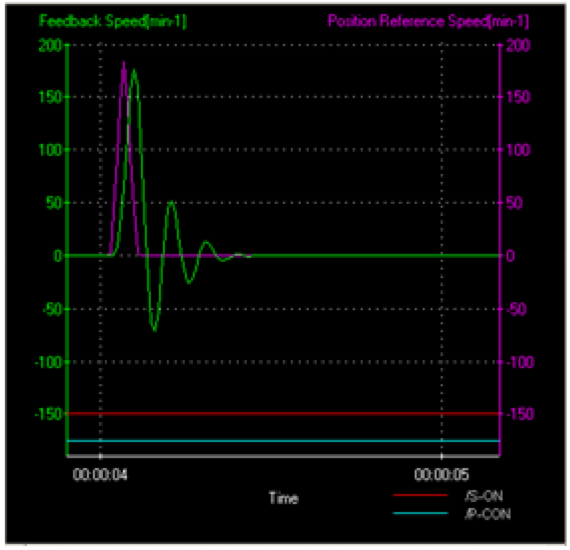

Figure 7: Untuned system (Purple plot: Reference velocity, Green plot: feedback velocity)

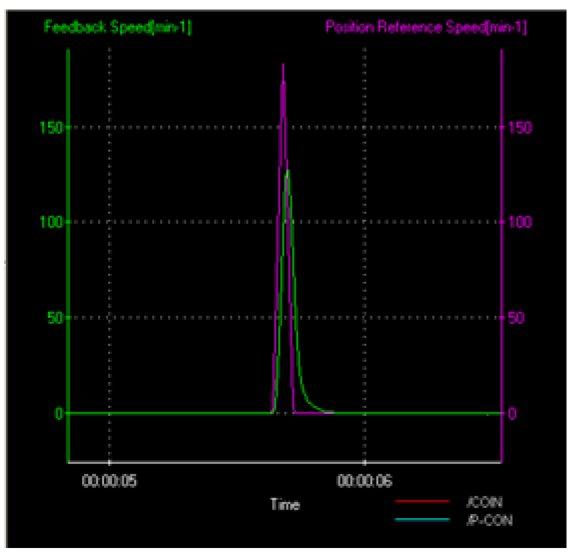

Figure 8: Tuning-less function enabled (Purple plot: Reference velocity, Green plot: feedback velocity)

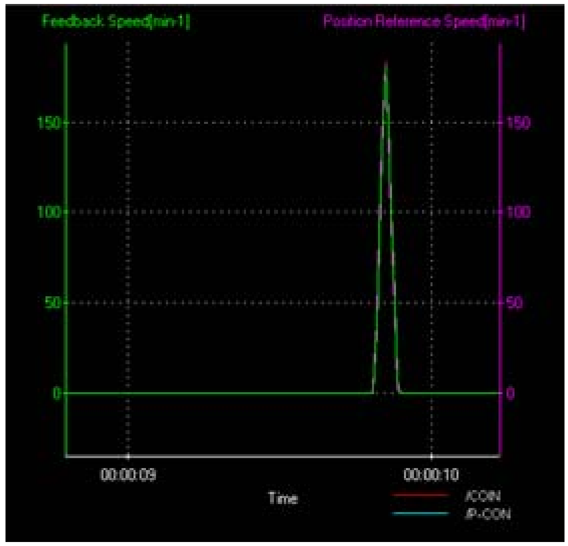

Figure 9: Autotuned system response (Purple plot: Reference velocity, Green plot: feedback velocity)

It can clearly be seen how the tuning-less function performs better than the untuned system. To go from the response on Figure 7 to the response in Figure 8 took only a click of the mouse to enable the tuning-less function. The superlative performance of the autotuning feature is shown in Figure 8. The feedback velocity is right on top of the reference velocity, so that they cannot be differentiated. To go from the response in Figure 7 to the response in Figure 8, only requires a few minutes of interactive work where the tool guides the user through the steps of autotuning. Figure 9 is an impressive response, which would be worthy of a day or so of an expert tuner's time. *This result can be achieved by a tuning novice in a matter of minutes.*

One Parameter Fine-Tuning:

One parameter fine-tuning is the next level of tuning, where the user can manually adjust the gains and filters. This feature is used to fine tune the response of the machine after the advanced autotuning has been used. Based on the tuning level desired by a user, seven individual parameters can be changed in an optimal manner through the adjustment of only a single "fine tune" parameter. Four tuning modes can be selected based on desired features like stability, responsiveness, or position overshoot suppression. A machine resonance filter selection can be determined according to the actual machine assembly. The notch filters found can effectively avoid areas of frequency resonance that can otherwise cause servo instability and inefficient performance. Experimental verification has shown that the one parameter tuning feature was able to cut settling time in half, compared to the settling time obtained after autotuning.

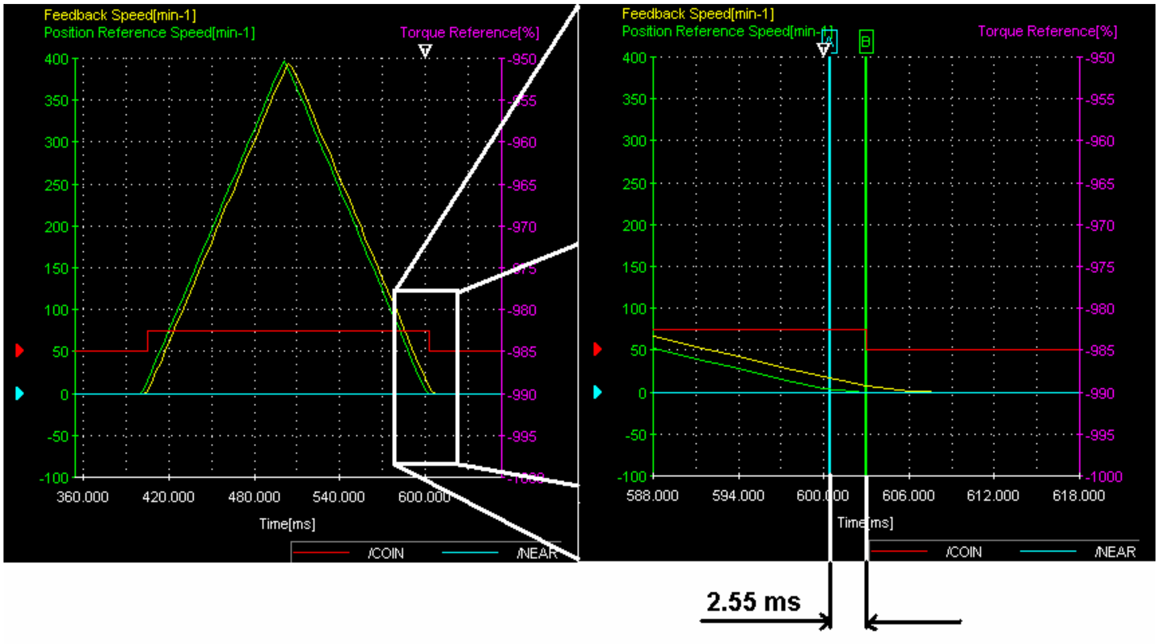

Figure 10: Settling time less than 4 msec with Yaskawa Sigma-5 servo

Figure 10 is an illustration that compares the reference velocity and the feedback velocity from a move that commands 400 rpm with a 20:1 load ratio. The figure on the right is the zoomed out version of the plot on the left. The vastly superior settling time of 2.55 ms obtained from an autotuned Yaskawa Sigma-5 servo system stands out.

Benefits of Yaskawa Sigma-5 servos when replacing stepper motors

1) The servos are easy to set up and tune, which saves startup and commissioning time, eliminating the primary pain of stepper-to-servo conversion.
2) Higher power density helps the machine builder swap a stepper with a servo more easily without having to redesign the machine to improve performance.
3) Wider torque ranges available at higher speeds, helping the machine accommodate a wider range of products
4) Higher speeds allow for higher productivity.
5) Yaskawa servos pay for themselves over time with high reliability, sturdiness, and performance.

Summary

Manufacturing today requires highly productive, flexible machines that perform consistently with minimum downtime. For this reason, many machine builders are switching from stepper to servo technology, but not without difficulty.

Yaskawa addresses customer needs from both a technology and quality standpoint. Yaskawa's quality driven ISO 9001:2000 approach ensures the highest reliability of any servo system manufactured today. This is the primary reason why Yaskawa is the largest producer of servos in the world, having installed more than five million systems worldwide. Yaskawa's newest generation Sigma-5 series servos employ cutting-edge technology that improves system performance and saves commissioning time for the user. This is especially important in a stepper-to-servo conversion scenario where servo system tuning expertise may not be available. Default tuning-less adaptive performance allows a completely "hands-off" approach, while the Sigma 5's configuration wizards allow non-experts to easily achieve high-performance system response.