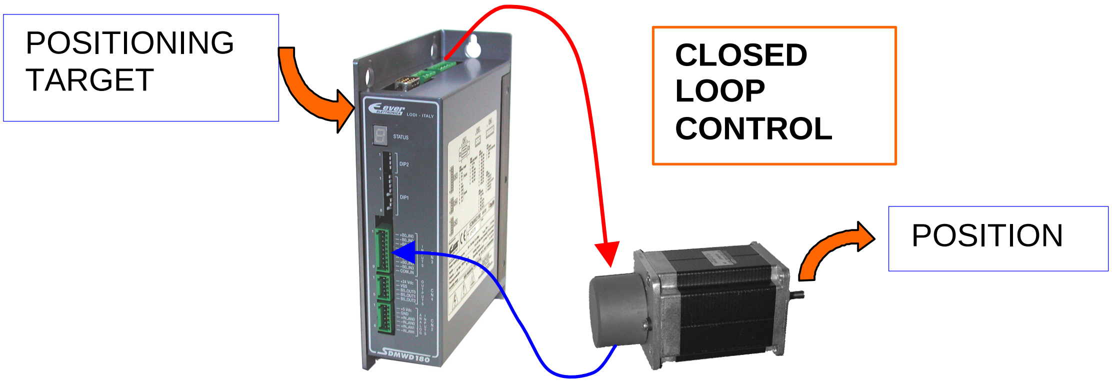
CLOSED LOOP SYSTEM AND FULL DIGITAL STEPPER MOTORS AND DRIVES.

SUMMARY
The existing habit of using the stepping motor in open loop cannot block the possibility of using this motor in close loop. The obtainable performances in this formality, from a stepping motor driven with an Ever drive full digital, shown that this system are able to make quickly stable, to the value desired, the following to the position, also in very strong condition, as for instance in direct drive at 2000 rpm, very hard also for brushless motors too. Besides, the stepping motor can be taken in high consideration also for very precise speed control, keeping its best performance and reputation for positioning control. Everything much more near to the costs of an open loop drives than the typical servo drive with equal power.

MECCATRONIC PLANNING
The condition of the existing market, force the machines to reach higher level of productivity and flexibility, increasing to a better quality the finished product. Moreover, on latest months, the planning of the more complex machines, brough to a technology integrations that allow the realisation of kinematism at high performances: real systems defined in meccatronic way and adopting strategies of integrated development among mechanics and electronics adjusted to the level of integration desired

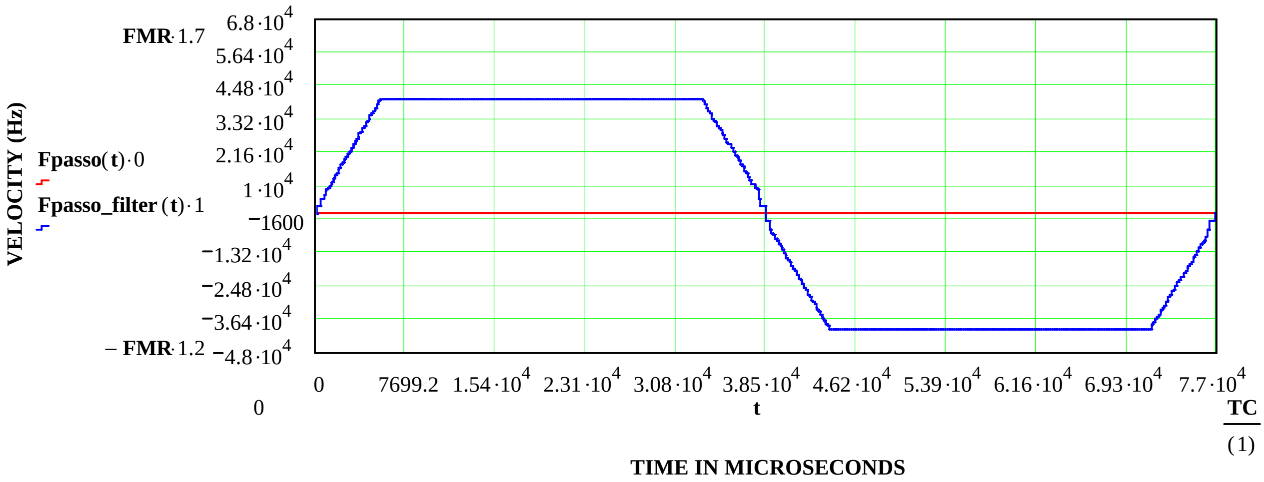
FULL DIGITAL DRIVES
Ever Elettronica proposes, for this purpose, new solutions for the development of the machines at high performances: the control of the stepping motor in closed loop. The close loop control implemented in to the Ever “full digital” drives of last generation, allows to increase the performaces of the servomotors, in relation to the positioning accuracy, to the dynamics (speed feedback) and to the efficiency.
The optimisation of the stepping motor performaces it’s gotten through the real-time management of the parameters of control of the motor (speed, current, positioning) and it represents a concrete answer to the increasing demand of improvement of the performances of speed control of the stepping motor in open loop, without the obligation to have to a meaningfully increase of costs, and consequently to compromise themselves to the related risks of changement adopting a motion control solution with brushless motor.
Infact, the new solution is perfectly interchangeable with the step by step solution already existing and easy to implemet and make the parameter referred to the application.

STEPPING DRIVES WITH CLOSE LOOP
The introduced motion control system, is realized fitting the motor with an incremental encoder with dependent resolution from the precision required by the application. Generally, thanks to the implemented sophisticated algorithm of control , it is possible to get good performances also with low cost encoder at low resolution (500 pps), avoiding the usage of an encoder with high resolution instead, for instance, what the brushless systems require to simulate the operation of a stepping motor. The introduced motion control system , is realized fitting the motor with an incremental encoder with dependent resolution from the precision required by the application. Generally, thanks to the implemented sophisticated algorithm of control, it is possible to get good performances also with low cost encoder at low resolution *(500* ppr), avoiding the usage of an encoder with high resolution instead, for instance, what the brushless systems require to simulate the operation of a stepping motor.



The encoder function doesn’t simply consist in the solution of the problem of the “bass of step”, checking the steps done at the end of the motor movement, but it guarantees precise positioning (the level of precision can be defined referring to the application) monitoring, in real time, the movement that the motor is able to do.

The system in closed loop, has been developed in order to get instant reactions related to the motor load variations, getting excellent result also for the typical inertial loads, without jeopardizing the good operation of the application. They avoid, in such way, the necessary over dimensioning for many stepping system in open loop and brushless, to guarantee the correct operation in all the load situations. In this way the searches of mechanical resonance (FFT) or analysis of form and phase, that are effected for the brushless drives, are not necessary. Besides, in presence of varying loads, this analysis is not usable, because the point of resonance changes in relation of the applied load to the motor, while the parametric system of the application foreseen for many brushless drives, through the automatic learning systems, is useful only in the case that the load of the system is not varying or, however, doesn't suffer meaningful variations during the operation.Through the closed loop control, it is possible to avoid the resonances due to the stepping motor frame, as for the brushless motor too, that is controlled, optimizing the angle of excitement, avoiding the rotor instability around the final position. To such characteristic, it is also added the possibility to make the microstepping , that thanks to the high resolution, it can push up to *25600* step/rev. The system is very flexible, being able the user to decide if the motor has to reach a certain position in sweet way (bow vibrations) or fast (high precision). All the necessary regulations for the control with feedback happen through the RS232/485 serial interface or through field bus CANbus in relation to the drive version used. Through such interfaces it is possible to make into parameter the specific data related to the control in closed loop, as all the data related to the drive and to the user application, since the control function in closed loop has been add to the firmware of which the Ever drives are equipped.



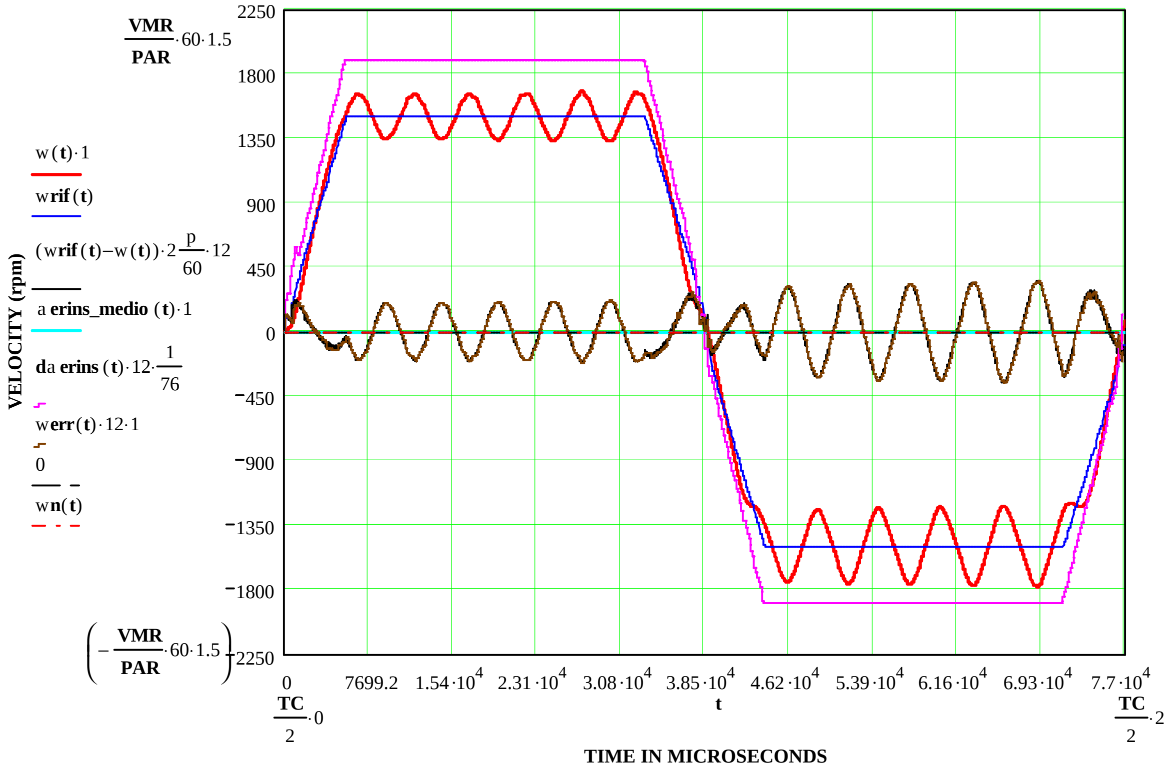
STEPPING MOTOR PERFORMANCES IN OPEN LOOP

Analyzing the behavior of a stepping motor driven in open loop following a typical speed profile, as for instance is shown in the above diagram, the speed of the motor doesn't converge to the value of reference, but continuous to oscillate around this last. Besides it is demonstrable that a variation of the inertia load or an increase of the holding torque, are able to bring the system in a instability condition. The most economic way, under these conditions, to bring the system in a stable state, is to act on the current and tension applied to the motor, or to slow down the operation speed. From the relation that show the acceleration of the motor, in relation of the torque Tm and Tr and the totai inactivity J

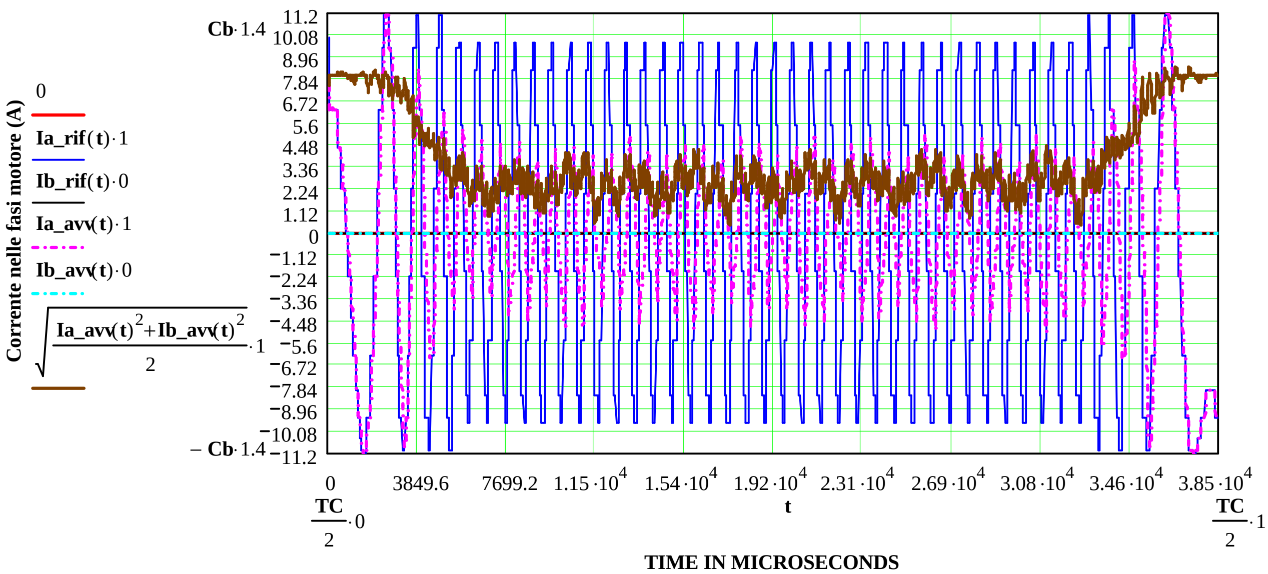
$Dw/dt = (Im-TR) / J$

It's clear why, in presence ofan exuberant torque Im in comparison to the load torque resistance shown in the formula by TR, or Tr variations, the speed of the motor use to have variations. In fact in order to get a sure positioning in open loop, it must be used a phase current (IF)able to guarantee a torque Tm that the motor doesn't stop also in variations of the load, being the widness of the developed torque by the motor expressed as: $Tm = Ke \times I_F$.

The following drawing, show the real state of the motor speed in such situation.



The following drawing underlines the state of the phase current that, during the movement, is not able to reduce during the movement at constant speed referred to the value used for accelerating the load.



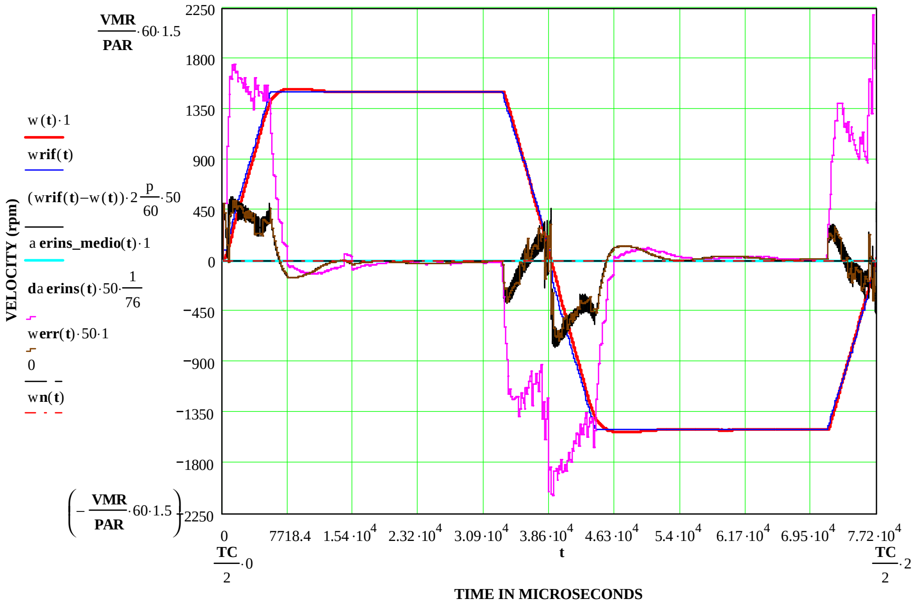
PERFORMANCES OF THE STEPPING MOTOR DRIVEN IN CLOSED LOOP WITH “FULL DIGITAL FIRMWARE” OF EVER ELECTRONICA

The main differences in performance for a full digital control of the stepping motors in closed loop in comparison to a control in open loop are related to:

- the precision of positioning;
- the stability of the speed;
- the phase current optimization of the motor;
- the less heating of the motor;
- the keeping of steps;
- the reduction of the power absorbed by the net;
- the less heating of the motor.

PRECISION AND STABILITY OF THE PERFORMANCES

The control in closed loop allows to get a precise and stable chase of the theorist speed profile, avoiding the oscillations of speed and reducing the instant error of the chasing. The resultant system is strong in comparison to the variations of load inertia and immune to the troubles of torque, for example caused from an unexpected increase of the attritions. It is important to notice as such a system, also if they introduced some prohibitive situations of load (over increase of the admitted parameters of some values of the application load), it is able to adapt the conditions of motor operation with the target of don’t lose the step and realize an autotunig. Here follow is shown the typical behaviour of a close loop controller, meaningfully better compared to an open loop drive referred to the same conditions of operation (speed, acceleration and inertia). The phase current value IF during the following of the position reference, is optimized through the relation as: IF = Kp * eq + Kd * deq / dt + Kf * d2eq / dt2 where the value eq, that show the error of position instant that is determined, as the derived deq/dt = ? R - ?, that show instead the instant error of speed, every 100 µs in way of allowing to the drive a very reactive and accurate chasing. Comparing to the most common brushlesses we can observe that the servo systems read aforesaid parameters middly every 250µs.



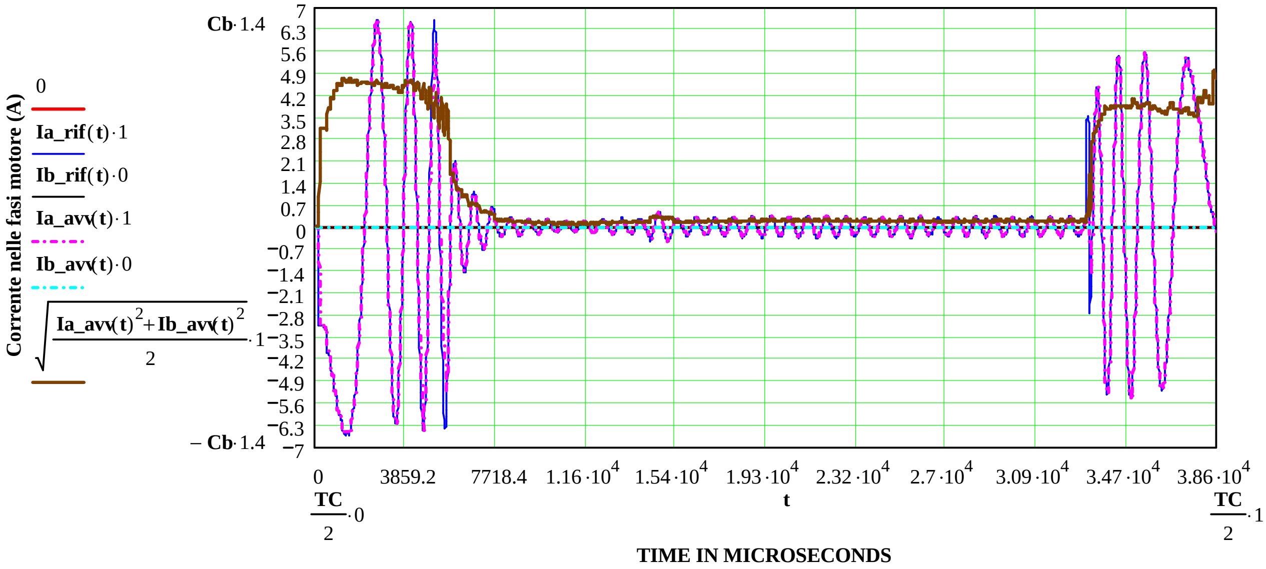
Since in a servo drive that checks the position of the motor, the precision of chasing of the positioning reference, also depends of the stability of the speed of the motor, in the way that if the speed is not firmly hooked the instant error of position to the value of reference it with the speed increasing, the importance of a cycle of fast regulation can be understood what that implemented the Ever Elettronica full digital drive.

Since with the closed loop control can be reached greater accelerations comparable to the obtainable in open loop, all this thanks to the holding of the synchronism of the motion in every condition of load, it is possible to increase the dynamic performances of the motor exploiting the characteristics of torque in optimal way and maintaining stable the motor answer, also in movements under the continuous fluctuations of torque demand.

OPTIMIZATION OF THE PHASE CURRENT OF THE MOTOR AND STEP HOLDING

The increase of the performances is also relative to the optimization of the current in the motor winding: when the reference of speed is hooked, in closed loop is pursued with one sensitive diminution of the winding current in comparison to the value disbursed during the acceleration.

The follows figure, underlines that with the same motion parameters and with the same analyzed motor, it's enough to feed lower current in to the dose loop motor then the open loop and get better dynamic performances.



REDUCTION OF THE POWER ABSORBED FROM THE NET AS THE HEATING OF THE MOTOR.

As positive consequences, we'll have the diminution of the lost energy in heat and therefore of the duty cycle temperature of the motor and no more generation of useless torque, that would be translated, as seen in open loop control, in needless continuous accelerations and decelerations of the motor. This characteristic is important especially in movements with cycles of continue movement where is possible to save considerable energy. From the last graph related to the instant current in closed loop, gotten planning a maximum value of current feeding, during the time of acceleration and deceleration of *5* Armses and a minimum current of 0 Arms, a value of medium current Irmsa says = 2,218 Arms for the phase A and Irmsb = 2,239 Arms for the phase B and the followings data for powers and raising of the temperature of the motor:

Absorbed Power = 19,132
Mechanicai Power = 11,47
Pj_diss = 7,662
DELTA_Ambient motor temperature = 15,324

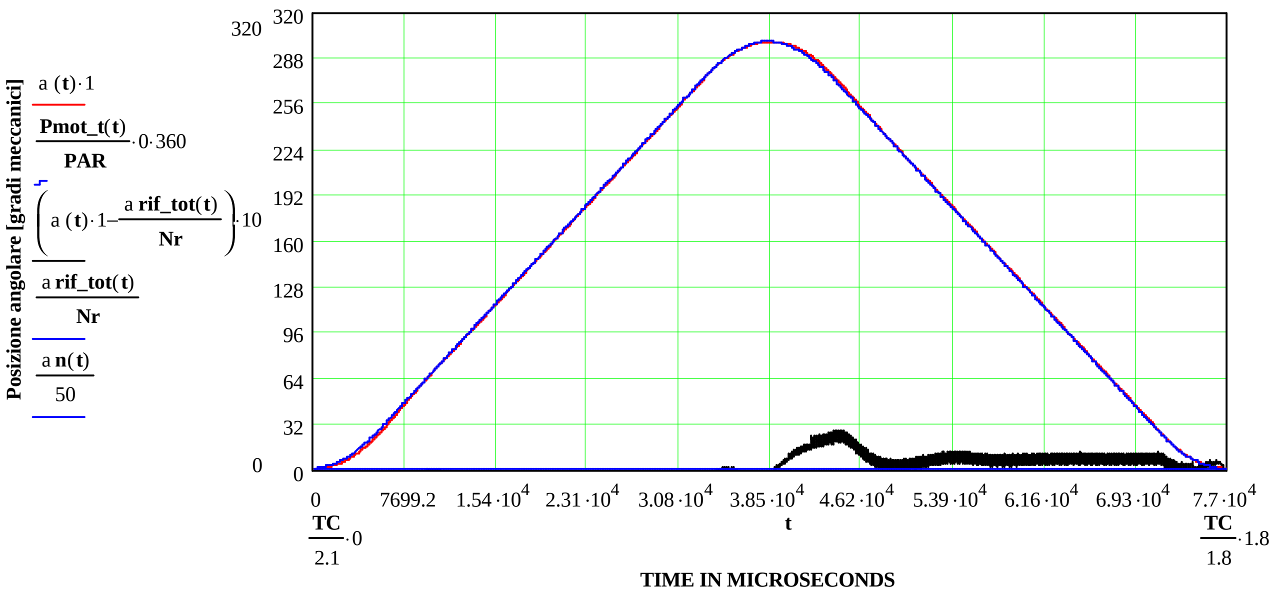
Having planned to supply a maximum current during the transitory ones of acceleration and deceleration, equal to 8 Arms and a minimum current supply to transitory exhaust equal to 7 Arms, from the former graphic related to the phase current in open loop, we can read, respectively for the phases A and B, the current Irmsas = 4.202 Arms and Irmsb = 4.261 Arms and the followings data for powers and the temperature raising of the motor:

Absorbed Power = 31,268
Mechanicai Power = 11,47
Pjdiss = 19,798
DELTA_Ambient motor temperature = 39,596

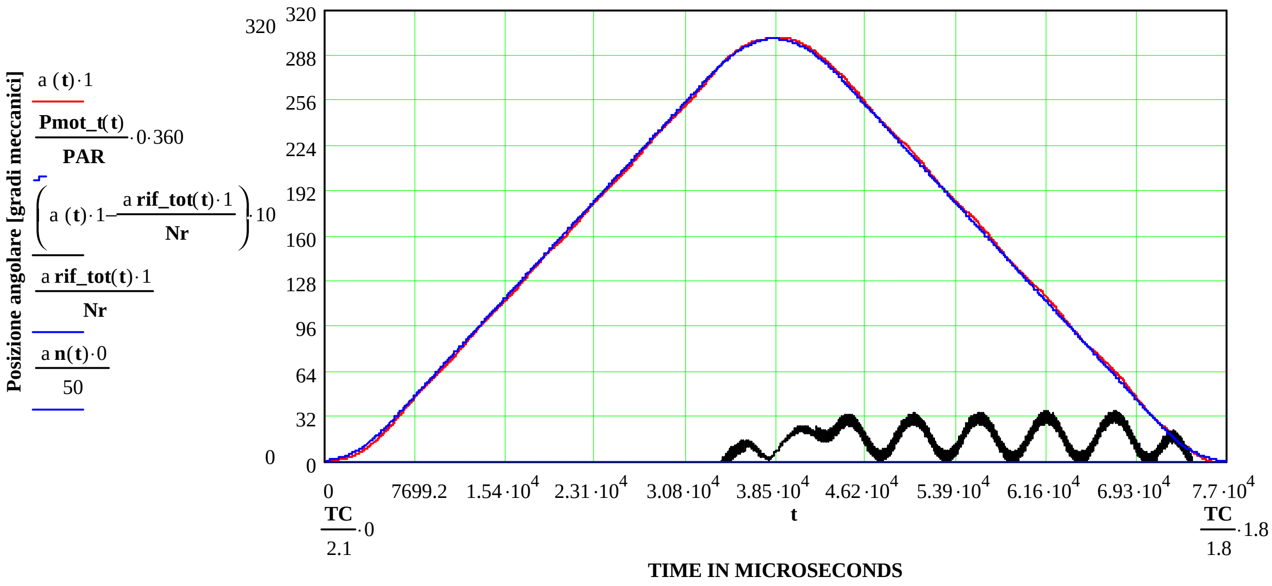
It's evident the difference among the two solutions in terms of "absorbed power" from the net, power dissipated (Pj_diss) from the motor and thermal raising of the same motor in comparison to the external environment to all the advantage of the closed loop solution.

PRECISION OF POSITION CHASING

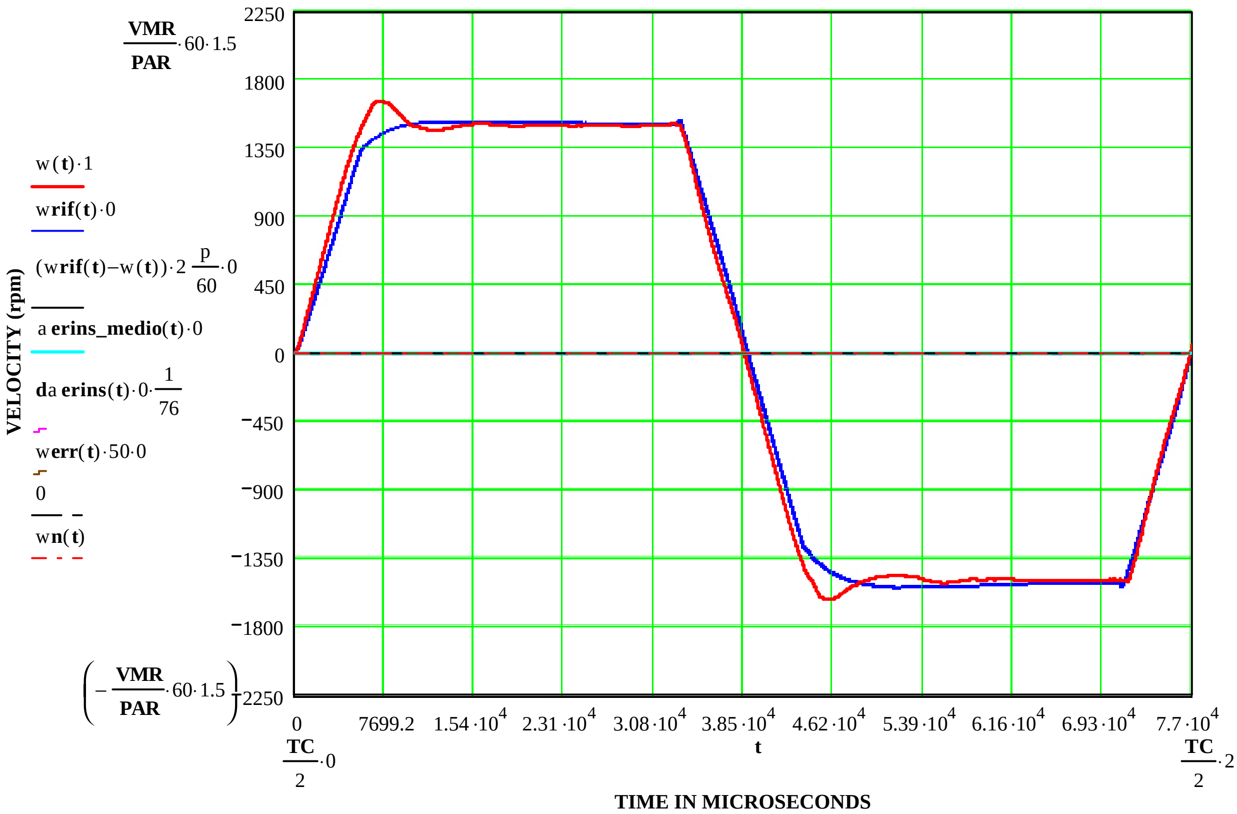
Thanks to the expression of the current algorithm of control, implemented by Ever Elettronica, proportional and derivative type, with feedforward of speed and acceleration and the frequency of error reading positioning and closing loop of the referred regulation, the position of the motor constantly results checked and correct. This is a characteristic important in terms of performances because in the machines, in which the shaft load of the motor it's not constant, it influence the quality of the work. It is important to notice, from the following graph, as the oscillations in the error of chasing, are damped after few cycles of regulation.



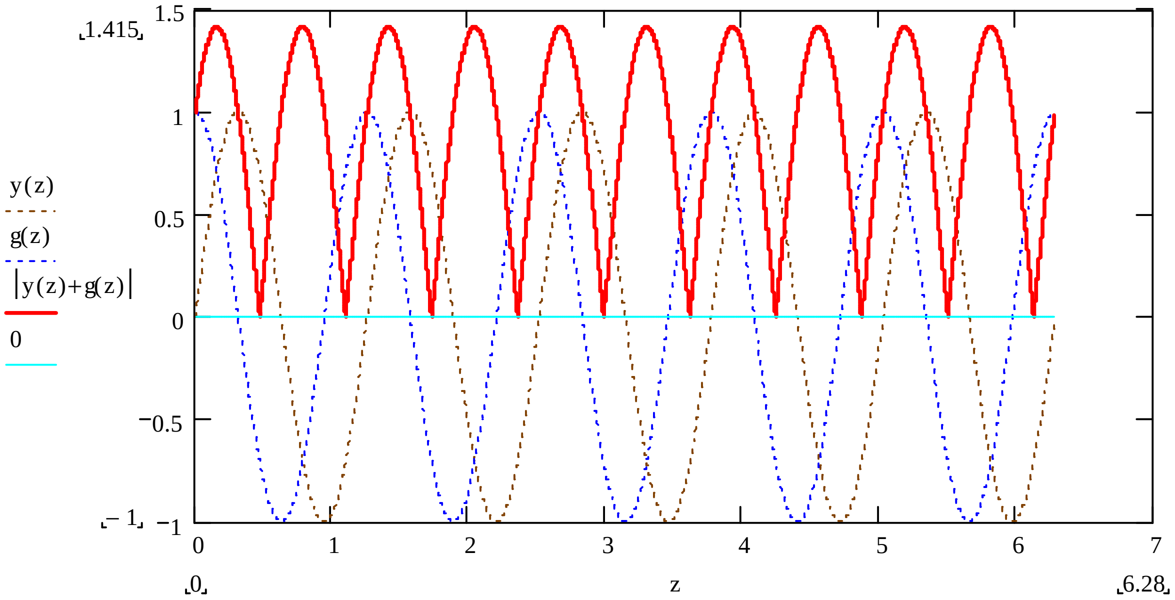
With the control in open loop, if necessary, a method to minimize the errors of positioning is also adopt damping systems of the mechanic oscillations ***being such solution*** it is not always usable both for cost and technical reasons, in applications that require high speed, precision and however for machines with varying loads.



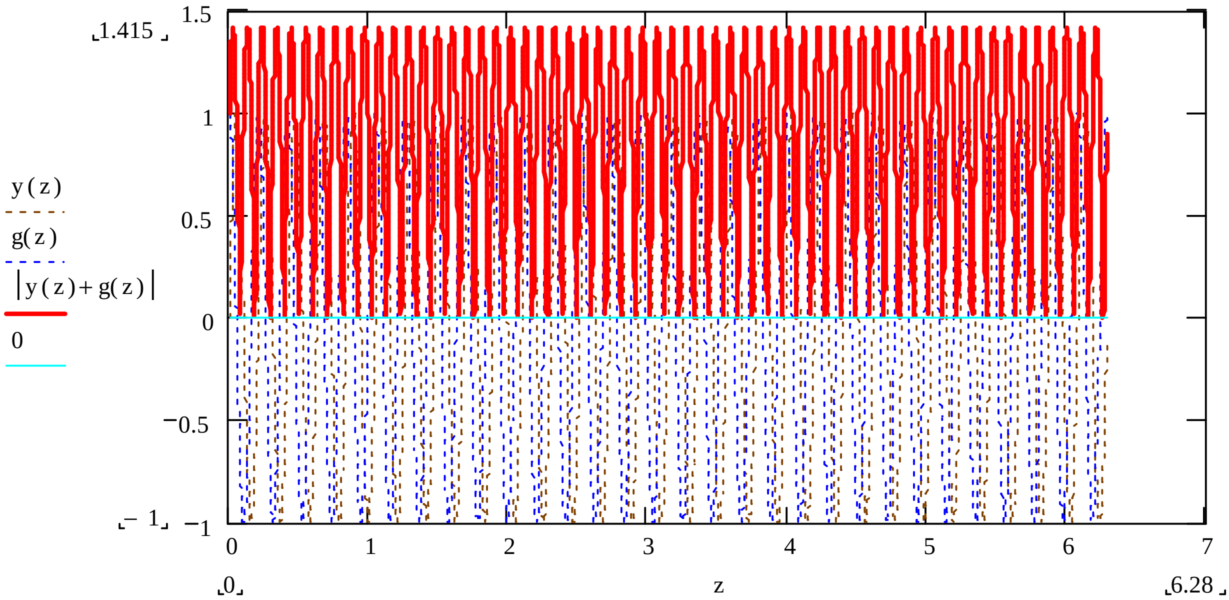
I COMPARE WITH THE PERFORMANCES TYPICAL OF THE BRUSHLESS SERVODRIVES
Analyzing the attainable dynamic performances with a control system of the movement with stepping motor in close loop, result evident some performances difference compared to the brushless servomotor.
The comparison, in the following figure, show a typical speed profile of a brushless motor during the pursuit of position reference: the delay of closing the control loop, together with the presence of an integral term of the position error in the formula of calculation of the winding current, type IF = Kp * eq + Ki * ? eq dt, it doesn't permit to reduce the arrangemen times and reductions of ***<u>sovraelongazione</u>*** values as much as those obtainable with the algorithms of stepping motor dose loop control implemented by Ever in which an used derivative term is present every 100ms, in comparison to the 250µs, typical for the servodrives with brushless motors.



A further advantage of the stepping servomotor, in comparison to the brushless type, it is consequent to the mechanics structures of the first one that introduces an elevated number of poles, usually 50 in a motor to 200 steps per revolution, in comparison to the number of poles of a motor brushless, typically equal to six.
Depending the torque ripple on such parameter, it results evident that the stepping motor introduces one alternate component of the torque with greater frequency in comparison to the motor brushless and it allows therefore a good control in the cycles of positioning.



Torque diagram for mechanical 360° in a 6 poles brushless motor.



Torque diagram for mechanical 360° in a 50 poles stepper motor.

The two curves above explain the fact that the torque in a stepping motor two phases is defined from the relationship Tm = Ia * Ke * sin(Nr*a) + Ib * Ke * sin(Nr*a+90) with typically Nr equal to 50, while in a brushless motor the torque is defined by the sum of three sinusoidal component desplaced of 120° and with typically Nr. equal to 6.

CONCLUSIONS

The existing practice to use the stepping motor in open loop, cannot and it doesn't have to obstruct the possibility to use such motors in closed loop. Such systems in fact, as the data above, result of Ever Elettronica experience, represent a tool, able to check with good performance the behavior of a dynamic system. Such systems, in fact, are able to make stable in a quickly way, to the desired value, the referred pursuit of position also under conditions of use that they would be binding for a motor brushless, especially under direct driving conditions to a speed of 2000 rpms . Everything at a costs level that are more near to the open loop drive then a common servodrive of equal power, aspect surely not negligible.

The closed loop control is an additional functionality on the way to be introduced in all the typologies of drives produced by Ever Elettronica, that will allow the end-users of their own drives in open loop to easily increase the performances of the machines without risks in every change of motor typology previously used with success.

Finally, the stepping motor that for constructive typology is one of the motor types more proper to be used as an actuator for positioning cycles control, to contained costs, can be taken in consideration also for very high precise control of speed, to contained costs.