

# NEW BENEFITS OF VECTOR CONTROL OF HYBRID STEPPER MOTORS WITH ENCODER

**Kai-Uwe Veregge,  
Jenaer Antriebstechnik GmbH  
Jena, GERMANY**



***Abstract** – Hybrid stepper motors of size NEMA 17/23/34 can be found in many applications in the automation sector. The benefits are low price and high continuous torque at low speed. The drawbacks are resonance oscillations at mid range frequencies, low accuracy if there is a permanent load torque active and overheating. The vector control of JAT controls hybrid stepper motors up to 3000 rpm in current, velocity and position. It eliminates the mid range resonance problem completely and with a 160k smart encoder from JAT it performs an excellent position stiffness. The overheating is controlled since the current is part of the feedback loops. This paper compares the main characteristics of both vector controlled brushless DC motors and hybrid stepper motors according to real industrial applications.*

## **I. INTRODUCTION**

Today's automation business is getting more and more a struggle to adjust the product portfolio to the cost-performance-reliability requirements (CPR-requirements) of niche markets. To be competitive 10 years ago it was okay to replace stepper system driven machines with newly coming up brushless DC systems to raise the overall productivity of the customer and also the price of the machine by factor 2. This picture changed, nowadays machine construction customers often complain about overcapacities; they want to use technology to save energy and to make the machine less expensive with the same performance.

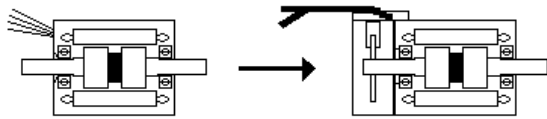
For this reason the Jenaer Antriebstechnik GmbH uses faster microelectronics to give normal hybrid stepper motors of NEMA 17/23/34 the performance and reliability of brushless DC systems. We have more than 6 years of successful experience in those fields where not power (velocity x torque) is the aim but:

1. low resonance excitation of load
  - a. in polishers
  - b. in image setters
  - c. in more-dimensional measuring machine
2. reduction of heat dissipation at point to point movement
  - a. in traversing drive in textile finishing
  - b. in vertical axis in storage systems
  - c. in intermittent operation in packaging systems
  - d. in format size adjusting in printing systems

## II. MAIN

But what does vector control of hybrid stepper with encoder mean?

At first we have to put an encoder to the stepper, raise the rigidity and prevent the shaft from moving axially (destruction of encoder) and mount shielded cables properly.



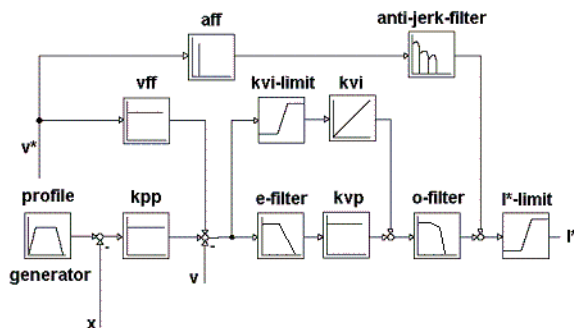
**Figure #1, Change of motor construction**

Therefore the stepper is called ECOSTEP® (encoder commutated stepper, Fig. #1).

Presently encoders with a resolution between 8k and 160k increments/revolution are being used. The algorithm works fine with at least 8k increments/revolution.

Looking at the control loop diagram of an ECOSTEP® drive (Fig. #2) we find an ordinary cascaded control loop of position and velocity with feed forward parameters vff and aff (with anti-jerk-filter) starting from a profile input  $v(t)$  and  $x(t)$ .

The control loop output is the nominal current  $i^*$ .

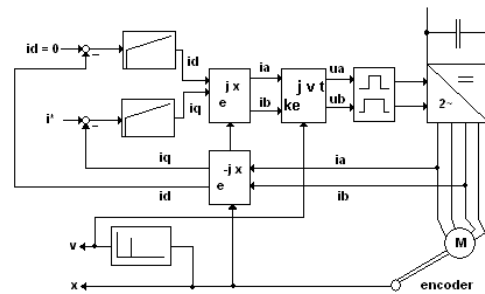


**Figure #2, Control loop diagram of ECOSTEP®**

To drive a 50-pole stepper in closed loop up to 3000 rpm it is necessary to make a current setting during 100  $\mu$ s. Fig. #3 shows the current vector control of a 2-phase stepper motor with encoder.

The vector control is related to the division of the nominal current  $i^*$  into the flux-rotating current  $i_d$  and the torque generating current  $i_q$ .  $i_d$  and  $q$  are calculated after an appropriate auto-phasing and is related to the position feedback. The aim is, to control  $i_d$ -value to zero and let  $i_q$  be the torque adjusting current. The vector control outputs are two voltages  $u_a$  and  $u_b$  related to the two phases A-/A and B-/B of the motor.

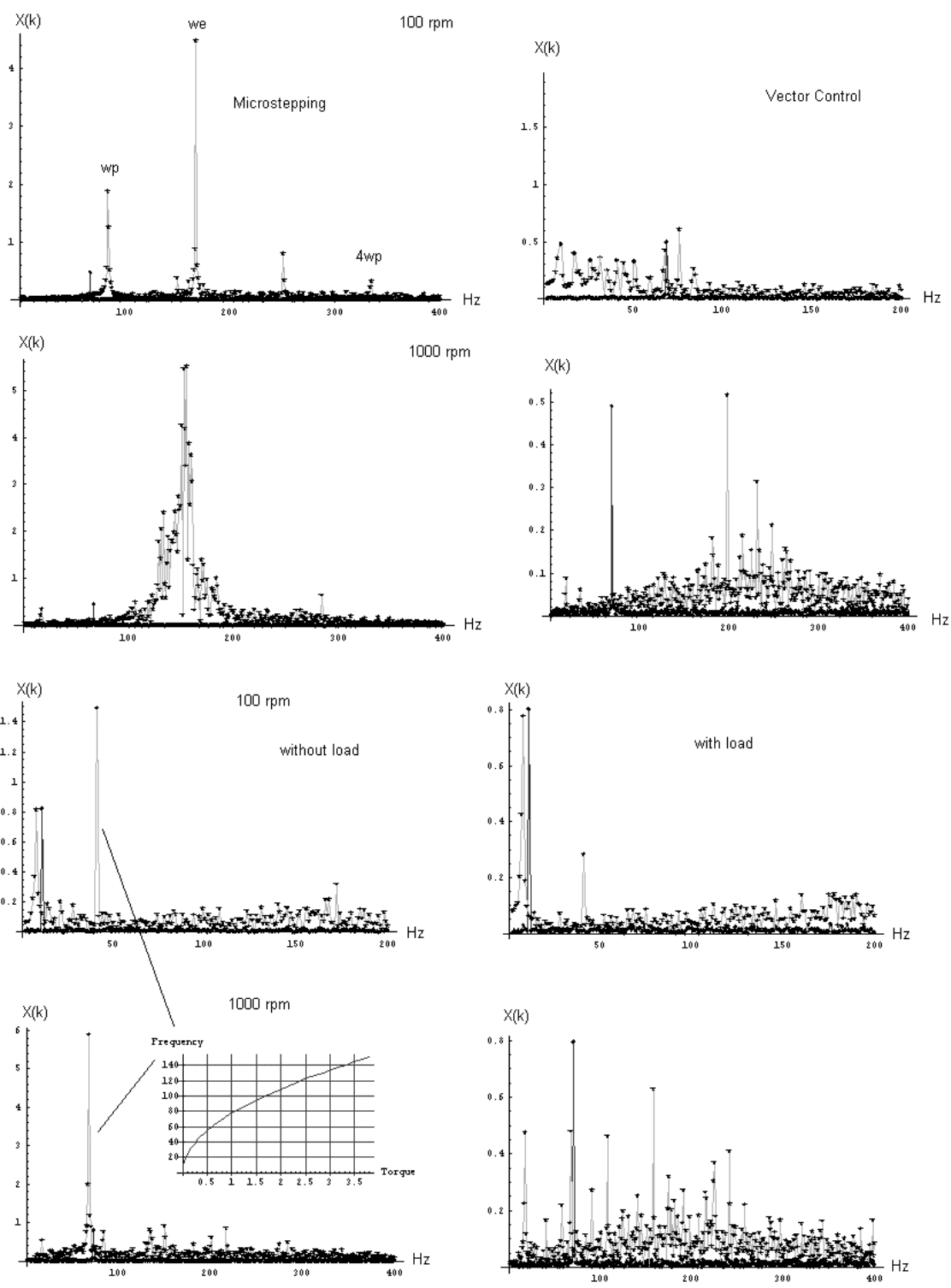
The phase currents are preshifted according to the velocity of the motor. This last step is not necessary for low-pole brushless dc motors but for hybrid steppers.



**Figure #3, Vector control of a 2-phase stepper motor**

To give an example how well this vector control works we use the fourier transformation of several speed signals. The fewer harmonics can be seen and the closer the spectrum is to white noise the smoother is the movement of the shaft.

Fig. #4 shows several digital fourier transformations of a stepper motor driven by microstepping and with vector control. The dark grey peak (for illustration), has always the same magnitude and lays at frequency of 70 Hz.



Figures #4 and #5, Fourier transformations of stepper (4 upper diagrams) and brushless DC motor (lower 4 diagrams)

Vector control is able to reduce the natural frequency “we” by factor ten, it is the same with the velocity proportional resonances  $w_p$  and  $4w_p$  (latter is called ripple). On higher velocities e.g. at 1000 rpm the natural frequency often causes the “falling out of step” of ordinary stepper motors. The resonance peaks according to the higher harmonics of the pole pair count ( $w \times p$ ) are damped by  $1/w^2$  (bode gain drop of a single-mass system with  $w > w_0$ ) through the mechanical plant, therefore they do not much interfere the motion over 300 rpm.

Vector control makes it possible to smooth down the frequency area until the plant’s deep path filter does it on the high frequencies.

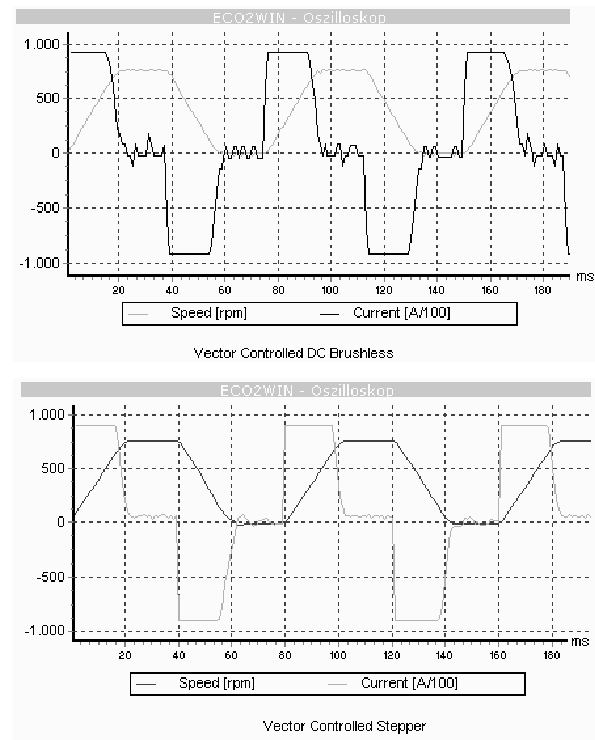
If we make the same transformation with 8-pole brushless DC motors of size 60 x 60 mm (2.3” x 2.3”) we receive the results shown in fig. #5.

For the brushless DC motor the torque current is not modulated to compensate the ripple of the motor. At 100 rpm the ripple  $w \times p$  is at 6.6 Hz and increases five times at 1000 rpm ( $w \times p = 66$  Hz). Depending on the size of torque there is also the natural frequency “we” of the motor. A stiffly coupled additional load (right diagram) of 35 times the motor inertia is needed to decrease the peaks as effective as with vector controlled hybrid stepper, that would also benefit of an additional load. A compensation is certainly possible but lowers the torque of the brushless DC motors.

Now we have analyzed the degree of synchronism between microstep and vector controlled stepper (ECOSTEP®) and brushless DC motors.

At next step we analyze the efficiency which is important for applications with high duty cycle. It is a common prejudice that a stepper gets hot easily. With vector control this is no problem, because the system acts as a closed loop system. In the following picture two motors (one of the most famous brushless DC

motor and one of the best-selling hybrid stepper motors) of roughly the same mechanical size NEMA 23 and mass of 1.5 kg have to accelerate and decelerate a directly coupled inertia of 3.4 kgcm<sup>2</sup> in intermittent operation (“machine gun operation”).



**Figure #6, Intermittent positioning (duty cycle 50 %)**

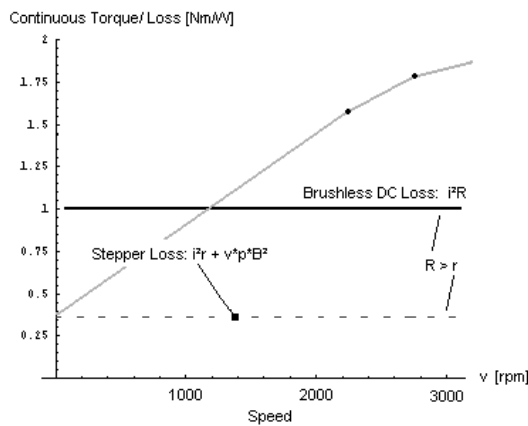
Both motors are isolated from any heat sink and the temperature is measured in steady state operation. We get the data shown in table #1 ( $\Delta T = T_{frame} - T_{environment}$ ).

The ECOSTEP® is 15 % - 30 % more efficient in the speed regime under 1000 rpm.

	$\Delta T$ brushless DC motor	$\Delta T$ ECOSTEP®
135 degrees in 60 ms (max. speed 750 rpm)	79 K	66 K
78 degrees in 40 ms (max. speed 500 rpm)	83 K	59 K

**Table #1, Rising of frame temperature**

This is one of the reasons why these motors are used in traversing or sewing machine drives in textile finishing. The situation is not astonishing if we look at the well known schematic drawing of continuous torque divided by the loss for stepper- and brushless DC motors (Fig. #7).



**Figure #7, Power losses**

### III. SUMMARY AND CONCLUSION

This paper shows that beside the advantages of more power per volume and higher speed of today's state-of-the-art BLDC-motors the push in microelectronics give motor constructions like hybrid steppers a comeback on motion control - not in the general scene but in those niche markets where the CPR requirements have to be optimized. "There's life in the old dog, yet".