Electronic Frequency Search

Compared to a conventional electromagnetic motor the Elliptec Motor is driven with a high frequency AC voltage. The direction of the movement, rotation as well as linear, is only depending from the applied frequency. There is one main frequency band in which the Elliptec Motor moves forward and another frequency band in which the Elliptec Motor moves backward. Within these frequency bands the speed of the Elliptec Motor varies with the frequency. Hence it is important to use those driving frequencies for forward and backward direction for which the speed reaches its maximum. These two frequencies in which the Elliptec Motor reaches its maximum speed in forward and backward direction are called the optimal driving frequencies.

Therefore it is necessary to find the optimal driving frequencies or at least frequencies which are close to the optimum. There are various ways to determine the optimal driving frequencies. In case a sensor feedback system is already included in the application this sensor feedback can be used. In this article a sensor less method will be described.

Frequency dependent velocity behaviour

Fig. 1 shows the typical frequency dependent velocity behaviour of an Elliptec Motor. The forward motion of the Elliptec Motor is in the frequency band of ~74 to ~83 kHz, the backward motion in the frequency band from ~95 to ~102 kHz. To get maximum speed the optimal driving frequencies in these two frequency bands need to be determined.

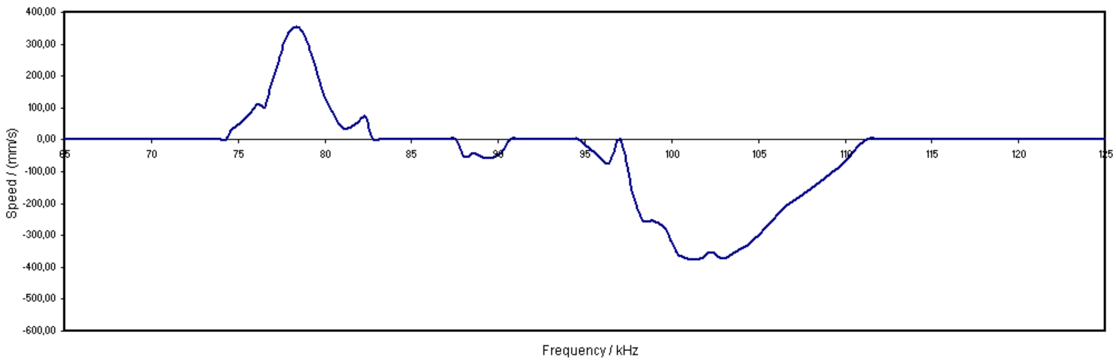

Fig. 1: Typical frequency dependent velocity behaviour

Electronic circuit with current measurement

Fig. 2 shows a typical driver circuit for an Elliptec Motor. The driver circuit consists of a half bridge MOSFET transistor configuration together with an inductance L2 in series with the Elliptec Motor. A microcontroller generates the Pulse Width Modulation (PWM) signal. A resistor R1 is used to measure the current in the half bridge configuration.

A low pass filter consisting of R2 and C1 is used to filter the ac part of the signal. The microcontroller uses this signal to measure the active current of the Elliptec Motor. Due to the low pass filter a stable signal is only achieved if the frequency is applied for at least 1ms.

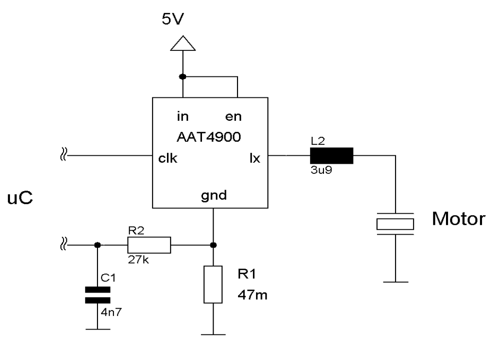

Fig. 2: Typical driver circuit for a 5V supply voltage

Frequency dependent current behaviour

The impedance of the Elliptec Motor is strongly frequency dependent. Especially in those frequency bands in which the Elliptec Motor vibrates in resonance. Therefore the impedance of the serial connection of the Elliptec Motor and the inductance is also changing with the frequency. These changes in the impedance influence the current running through the Elliptec Motor. It is possible to use the frequency dependence of the current to find driving frequencies close the optimal driving frequencies.

Fig. 3 shows the same typical frequency dependent velocity behaviour as in Fig. 1 together with the velocity dependent current behaviour.

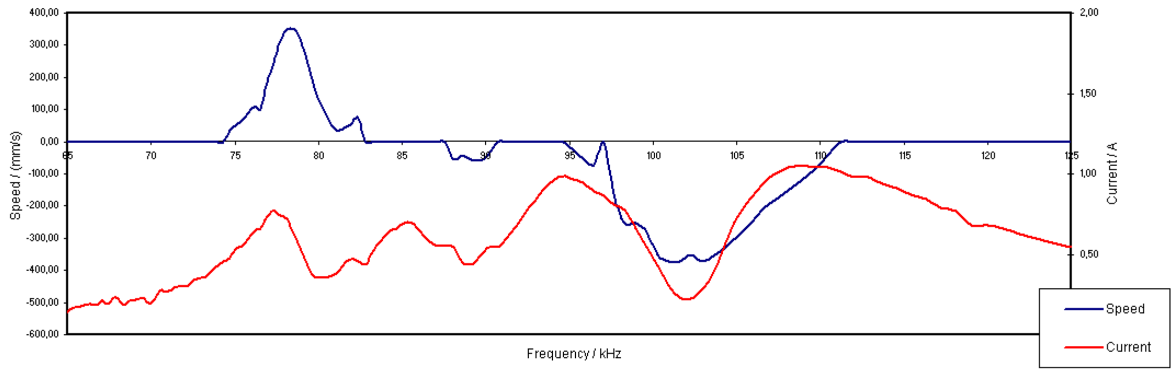

Fig. 3: Velocity and current dependent frequency behaviour

The Elliptec Motor is electrically mainly a capacitance in the order of magnitude of 500nF formed by the multilayer piezo stack. This capacitance together with the inductance L2 results in a series resonant circuit. The current of this serial resonant circuit drops off a low and high frequencies. The resonant frequency of the serial resonant circuit consisting of the Elliptec Motor and inductance L2 is chosen in such a way that close to the optimal driving frequencies the voltage and the current at the Elliptec Motor increases. If the Elliptec Motor would be replaced by a capacitance with the same value, the current would have its maximum around 90 kHz and would drop off at lower and higher frequencies.

In comparison with a capacitance the impedance of the Elliptec Motor changes drastically around the optimal driving frequencies. Close to these frequencies the current therefore drops off significantly.

Between the main two frequency bands of the forward and backward movement a small third frequency band can be recognized. The Elliptec Motor will move also within this frequency band but the resulting speed is very low. In Fig. 3 this small third frequency band can be recognized.

Frequency detection by current measurements

The drop off of the current close to the optimal driving frequencies allows finding driving frequencies close to the optimal driving frequencies.
In this article the frequency search is split in two parts:

- The two main frequency bands are detected in which the Elliptec Motor moves forward and backward.
- Within the two frequency bands the algorithm will be explained how to find those frequencies close to the optimal driving frequencies.

As explained above close to the optimal driving frequencies the current drops of at lower and higher frequencies. More detailed tests show that for both cases, in the forward and the backward frequency band the optimal driving frequency is always in that sequence where the current drops with increasing frequencies. The first step is to search for sequences in which the current decreases.

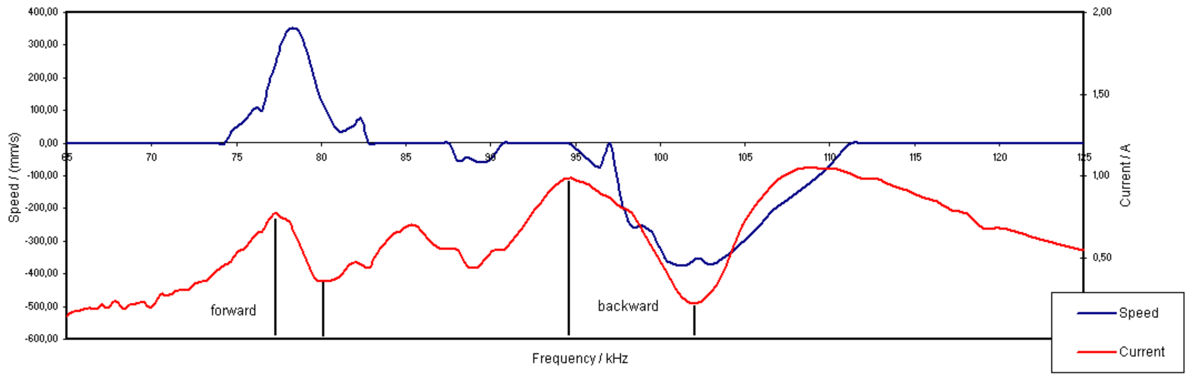

Fig. 4 Result of the first step of the frequency search

Following should be considered:

- Looking more in detail to the frequency dependent current behaviour, within the complete frequency band there are multiple smaller sequences in which the current decreases with increasing frequencies. These small sequences should be eliminated in the search. Detailed investigations have shown that if the change in current is smaller than 320mA (or 15mV at the current sense resistance) this sequence is not one of the two main frequency bands in which the Elliptec Motor moves forward or backward.

- The small third frequency band between the two main frequency bands needs to be eliminated as well in the search. One way to do this to split the search for the two main frequency bands in two parts. The first part will start at the low end of the frequency band (74 kHz) and look for sequences at increasing frequencies in which the current change is at least 320 mA[1]. The second part will start at the high end of the frequency band (110 kHz) and look with decreasing frequencies to sequences in which the current change is at least 320 mA. The advantage of this method is that the small third frequency band will never be passed through.

- The influence of interferences on the measured voltage needs to be avoided. Especially the determination of the change in the current needs to be taken care of. One way to eliminate the interferences on the measured voltage is continuously updating the minimum value of the current while passing through a decreasing current sequence. In case this value is lower than 100 mA the decreasing current sequence came to an end. The absolute value of the decreasing sequence is the difference between the maximum and minimum value of the current.

The same considerations apply starting from the high end of the frequency band while decreasing frequencies.

The above explained algorithm determines the two main frequency bands in which the optimal driving frequencies can be found. In the second step two driving frequencies are determined which lie as close as possible to the optimal driving frequencies in which the Elliptec Motor reaches its maximum forward and backward velocity.

Looking to the frequency band for the forward motion, the frequency at which the gradient of the current change reaches its maximum lies very close to the optimal driving frequency for the forward movement. Fig. 5 shows the calculated values of the current gradient and the resulting forward driving frequency which is close to the optimal forward driving frequency.

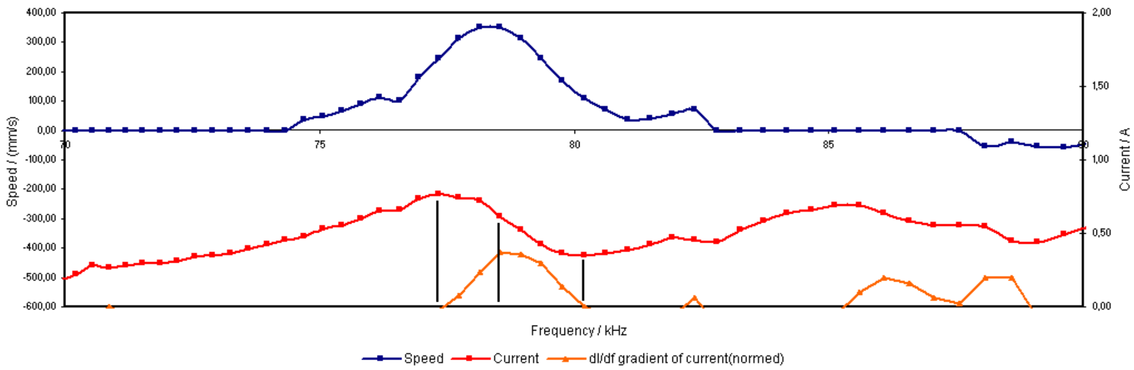

Fig. 5: Current gradient for the frequency band for forward motion

In case of the frequency band for the backward motion the gradient of the current within the decreasing current sequence stays often roughly the same. Detailed investigations suggest that close to the right end of the falling sequence an appropriate frequency can be found which lies very close to the optimal driving frequency for the backward direction.

One way to do this is to look at the right end of the falling curve for such a frequency at which the gradient of the falling current does not increase significantly. In case the value of the gradient does not double anymore the search ends.

[1] To avoid the first falling current sequence caused by the band pass effect of the inductance (from 125 to 108 kHz in Fig. 4) one possibility is first to look for the maximum frequency at which the current gradient is positive and start looking from this maximum frequency downwards.

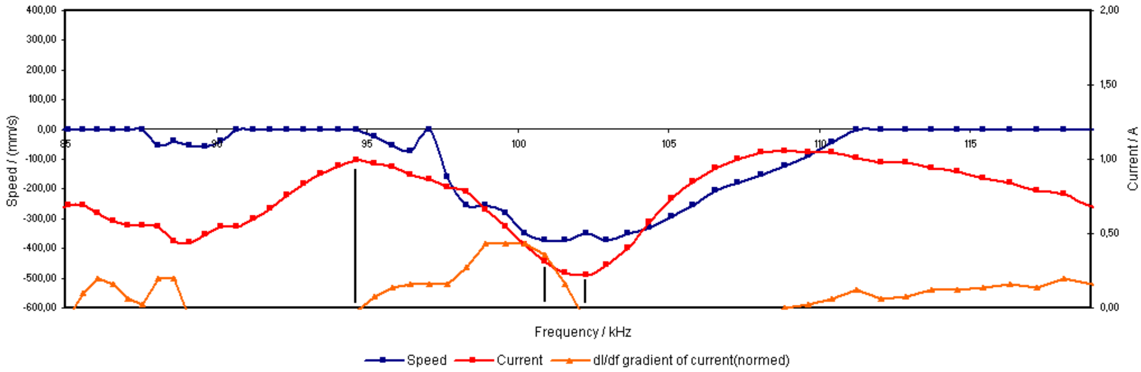

Fig. 6: Current gradient for the frequency band for backward motion

In Fig. 6 the current gradient is shown for the frequency band for backward motion and the result of the search is shown. The current gradient does not reach its maximum. The search comes to an end once the value of the current gradient is lower than twice the gradient value of the previous frequency.

Appendix

Trademarks

Elliptec™, Elliptec Motor™, Elliptec Minimotor ™, Elliptec Actuator™, Elliptec Module™, Elliptec Controller™ are trademarks of Elliptec Resonant Actuator AG.

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