# HIGH-PERFORMANCE MOTOR SYSTEM FOR WASHING MACHINES

**by Motor Control Competence Center**

## INTRODUCTION

Due to increasing consumer awareness of the need for preserving the environment and reducing greenhouse-effect gas emissions, washing machine manufacturers have undertaken advanced studies over the past few years that are designed to reduce the water and power consumption of their machines. They have also been encouraged to do this by European and American governments who have passed legislative measures both in technical fields as well as in the field of consumer information.

These energy saving measures involve improving the performance and efficiency of the types of motors used.

With a reduction of 200 Watts-hour per wash load (not including drying process), 300 cycles per year and 60 million washing machines sold each year worldwide, the potential amount of energy saved adds up to 4 billion kWh, i.e. approximately 4 million tons less of carbon dioxide in the atmosphere. Accumulated over three years and applied to refrigerators and household air-conditioning systems in the same manner, it is estimated that 200 million tons of carbon dioxide emissions can be eliminated. This would help to efficiently reduce the harmful consequences of the greenhouse effect.

For all these reasons, STMicroelectronics, in collaboration with major market players, has been driven to develop electronic motor control components that improve the output of equipment and also significantly reduce acoustic noise levels. These benefits are greatly appreciated by consumers.

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# 1 RECENT DEVELOPMENTS IN MOTOR TECHNOLOGY

Three-Phase Induction motors are associated with digital power inverters, which are used to continuously adjust the stator frequency and stator flux as a function of the load. Their windings are connected to the inverter outputs that perform the DC/AC conversion.

This motor system has many advantages, as described below, and will become the major motor system for "green" machines.

The measurements given in this document have been carried out using a SELNI motor, reference: AHV 2-42 (see Appendix).

# 2 BENEFITS OF THE NEW-GENERATION OF SEMICONDUCTORS

(Specifications and application notes are available at: http//www.st.com)

Over the past few years new semiconductor families have been developed and the cost of inverters has been reduced so that it is now compatible with household applications. These inverters are going to be used on a large scale not only in household washing machines, but also in refrigerators, heating and cooling systems or even kitchen appliances and vacuum cleaners.

This has been made possible through the development of the following product families:

## 2.1 INSULATED GATE BIPOLAR TRANSISTORS (IGBT)

These are MOSFET-type vertical power components that are equipped with an additional epitaxial layer to provide it with bipolar characteristics. It has the advantage of both insulated-gate components (low auxiliary control current) and those with bipolar transistors (low direct voltage drops by injection of minority carriers).

It is now available with an ultra-fast-speed anti-parallel diode in a fully insulated TO220-type housing which makes it much easier to assemble (Example: Refer to STGP3NB60HDFP / STGP7NB60HDFP on www.ST.com).

## 2.2 HIGH VOLTAGE INTEGRATED CIRCUITS

The DC voltage of a power inverter is approximately 300 Volts. Of the six power components that are used, three are referenced to the motor phases and are called "floating". Therefore high-voltage IC technology is required for interfacing the microcontroller with the control gates of these power components. This is now available due to the presence of L6384 / 85 / 86 / 87-type interface circuits. Note that for lower voltage applications, the L9931 offers an interesting six-switch interface and the L6234 a fully integrated Power stage.

## 2.3 DEDICATED MICROCONTROLLERS

Today, digital motor control units that use dedicated microcontrollers are totally perfected and offer adaptation and development capabilities that the old analog systems never provided. STMicroelectronics offers two 8-bit and 8/16-bit microcontroller families that are perfectly adapted to the requirements of modern household applications, combining high-performance and low cost.

As an example, the ST72141 is dedicated to controlling synchronous motors with or without sensors, while the ST92141 is more specifically designed for controlling asynchronous (induction) motors.

The ST92141 has been used in this washer drive application. It has six PWM outputs dedicated to driving the six Power switches and a tachometer generator input to measure the motor slip in real time. Its internal clock frequency is 25MHz that enables the generation of 1024 different levels for wave shape synthesis keeping acoustic noise inaudible. The dead time required for driving the power stage is programmable.

This product is available in EPROM, OTP and fast ROM version with 16K bytes of program memory, 512 bytes of RAM and 224 general purpose registers that can be freely used as accumulators, address pointers or registers. An 8-bit A/D converter and an additional independent 16-bit timer makes it possible to handle further control functions such as temperature or pressure regulation.

The ST92141 has been designed to provide robust performance in cost-sensitive applications. Features such as hardware watchdog timer, low voltage detection circuit, an asynchronous emergency input and high hysteresis inputs support enhanced noise immunity

## 2.4 SMART POWER COMPONENTS

Another factor that reduces the cost of these inverters resides in the possibility of integrating the auxiliary supply function onto a single silicon chip. Resulting from advances in MOSFET and bipolar power technology, various product families are used to combine both power and control functions on a single silicon chip. The VIPER12 is an example of this type of circuit. It provides cost effective ways to supply 15 V supplies directly from the mains.

# 3 SLIP CONTROL OF 3-PHASE INDUCTION MOTORS

## 3.1 PRINCIPLE OF INDUCTION MOTOR SLIP CONTROL

The motor efficiency curve versus torque shows a maximum value for a given voltage (see Figure 1.). The most efficient and optimum operating point is located somewhere at the upper right part of the curve that sets an optimum slip. The motor can be operated at its maximum performance level by selecting the optimum slip value and deducting the stator frequency. This is calculated as follows:

Stator Frequency = Rotor Frequency + Optimum Slip

All that remains to be done is to adapt the motor flux to the load line variations, which is done by regulating the motor voltage to keep the slip constantly at its optimum value. When the load tends to move the slip away from this value, the inverter immediately adjusts the motor voltage so that the slip remains at its set point.

In case of excessive load variations, the instantaneous slip is limited and the stator frequency is decreased to prevent loss of control. This avoids generating torque peaks that are source of disturbing acoustic noise.

## 3.2 RESULTS

Figure 2. shows the maximum slip variation at its set-point value in an application for a horizontal-axis washing machine. Using the most critical operating conditions, the washing machine was loaded with 2.5 kg of terry-cloth towels and 17 liters of water. The slip control gain was set so as not to react abruptly to the load torque variation, in order to reduce the acoustic noise of the motor / pulley / drum assembly as much as possible. The set-point value is 3Hz in Figure 2..

Figure 3. shows the same curve but the set point is now adjusted from 3Hz at low speed to 6Hz at medium speed and 8Hz at maximum speed.

# 4 APPLICATION OF A DIGITAL SLIP CONTROL DEVICE TO A WASHING MACHINE

## 4.1 EFFICIENCY IMPROVEMENT

The use of an automatic control device for maintaining the slip at its optimum value means an optimum performance of the motor regardless of its load. This is implemented with the ST92141 dedicated microcontroller that comes with a complete software library. All the software needed to performed high efficiency operation is available in this library.

The curve shown in Figure 4., measured on a test bench, shows in abscissa the load torque at the wash-cycle speed, and in ordinate the value of the motor + drive efficiency (lower curve), as well as the mains input current and Power (upper curves). Note that the total efficiency of the system is almost independent of the load in the useful speed range and optimum for this very low operating speed.

Table 1 compares the power consumption during the wash-cycle and the spin-cycle of a brush universal motor with that of a 3-phase brush less induction motor. The induction motor was used in compliance with the conditions specified in section 4 and highlighted a substantial gain in consumption.

One of the benefits of this excellent efficiency is reflected by the small and cheap heatsink resulting from the low level of power losses.

## 4.2 REDUCTION OF ACOUSTIC NOISE

It is well-known that the use of a brushless motor effectively eliminates noise related to its operation, especially during high-speed spin cycles.

Moreover, the slip control device is used to limit the instantaneous motor flux to a low or middle rate while keeping it independent from voltage variations of the mains supply. This means a perfectly silent operation of the motor; free of all 100 Hz noise and torque peak noise that may be encountered in vectorial control devices. The noise of the motor / pulley / drum assembly is therefore substantially reduced.

Finally, these motors have high torque capabilities, and the transmission ratio of the pulley can be significantly reduced as well as the associated noise.

## 4.3 HIGH-SPEED OPERATION

The speed of 3-phase brushless induction motors is only limited by mechanical considerations such as the quality of their bearings and the alignment of their rotors. The electronic control unit used in this study easily reached a speed of 20,000 r.p.m. and still running with the corresponding optimum slip. Table 2 shows the total system efficiency at high speed for different torques. The excellent efficiency of 78% keeps the input power at a reasonable level which is determinant to limiting the cost of a harmonic corrector (if used).

Figure 5 shows the very good linearity of the power control that reflect the richness of the system.

## 4.4 CONDUCTED EMI

A new gate drive topology has enabled to prevent any recurrent cross-conduction while regulating the switching dV/dt. This brings several advantages:

- switching losses are limited to the minimum required to achieve a targeted dV/dt

- dV/dt is almost independent of operation conditions and adjusted to set the EMI spectrum below the limit.

As a consequence it has been possible to meet the standard requirements using only the usual washer input filter. Figure 6 shows the conduced noise at the washer input in wash-cycle.

## 5 CONCLUSION

This system has shown that the performance of a 3-phase induction motor associated with a dedicated digital controller greatly exceeds that of universal brush-type motors.

The recent introduction of a new dedicated ST92141 microcontroller, as well as new control device technology for motor performance have led to lower prices for 3-phase induction motor + electronic drive assemblies to the level of standard solutions.

This is achieved by optimizing all the parameters of the system and in particular in implementing a slip control regulation together with a new gate drive topology.

As a result, these assemblies will be implemented in the near future, which will result in surprisingly lower acoustic noise levels for washing machines, as well as shorter wash / spin cycles and reduced power consumption.

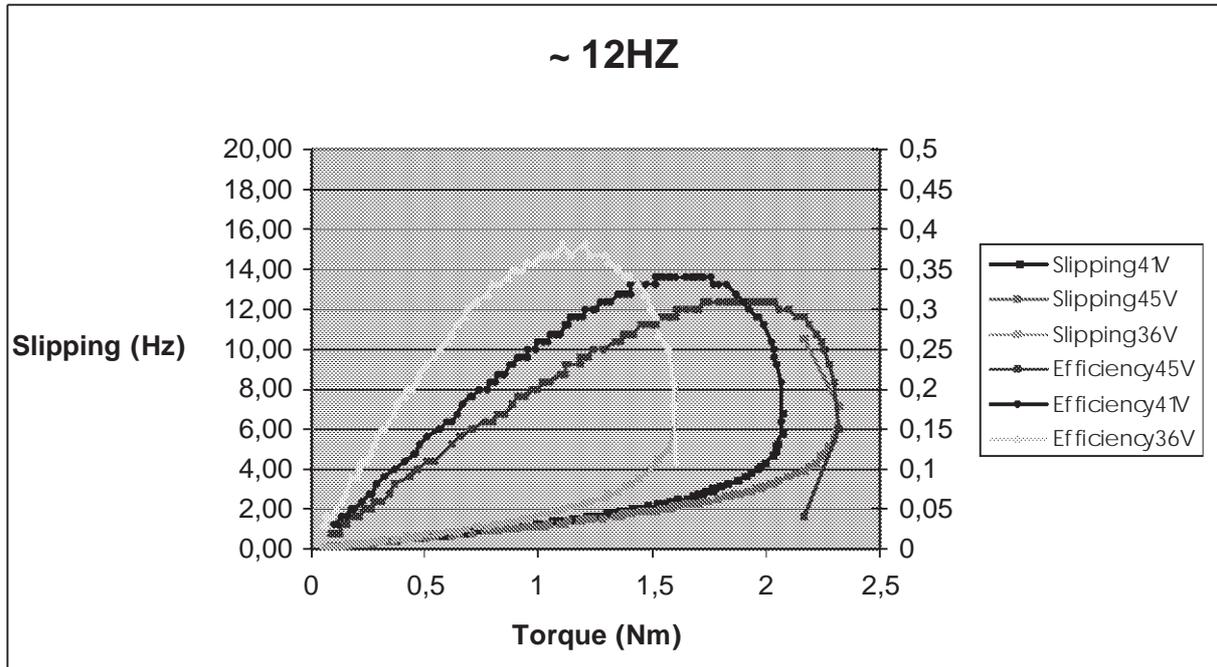**Figure 1. Induction Motor Torque versus Slip Characteristics**



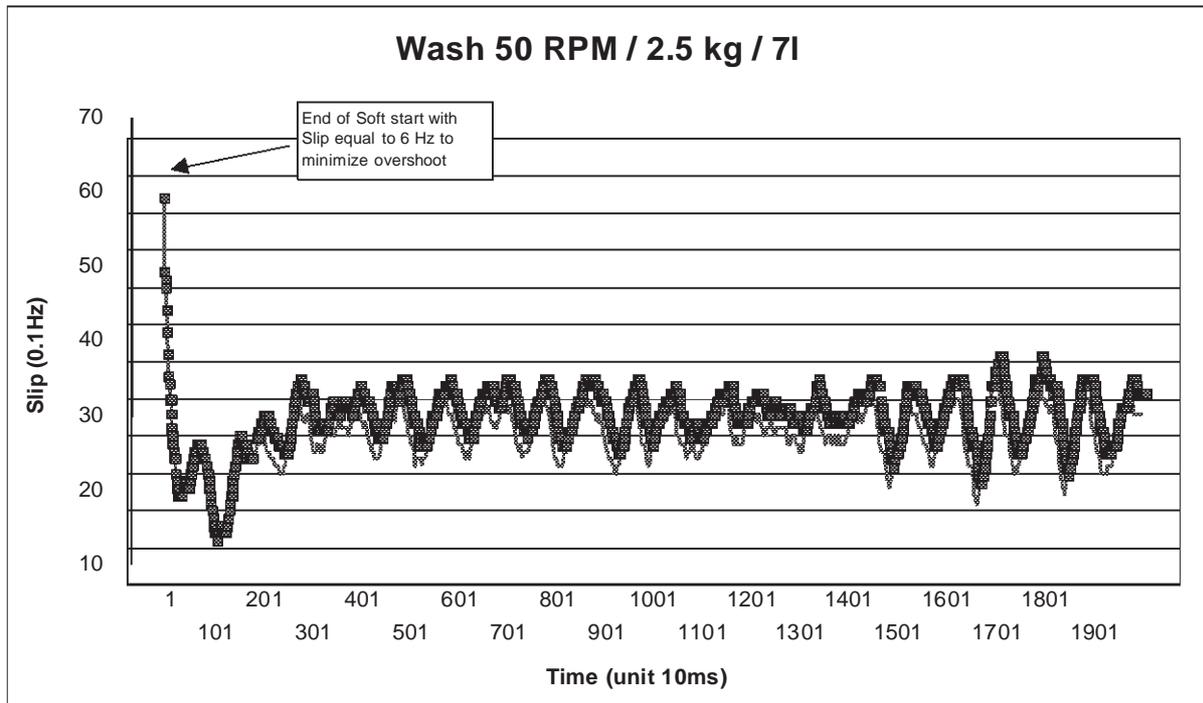~ 12HZ

**Figure 2. Slip control during washing**



Wash 50 RPM / 2.5 kg / 7l

End of Soft start with Slip equal to 6 Hz to minimize overshoot

**Figure 3. Slip control during balancing ramp**



Balancing cycle / 2.5 kg
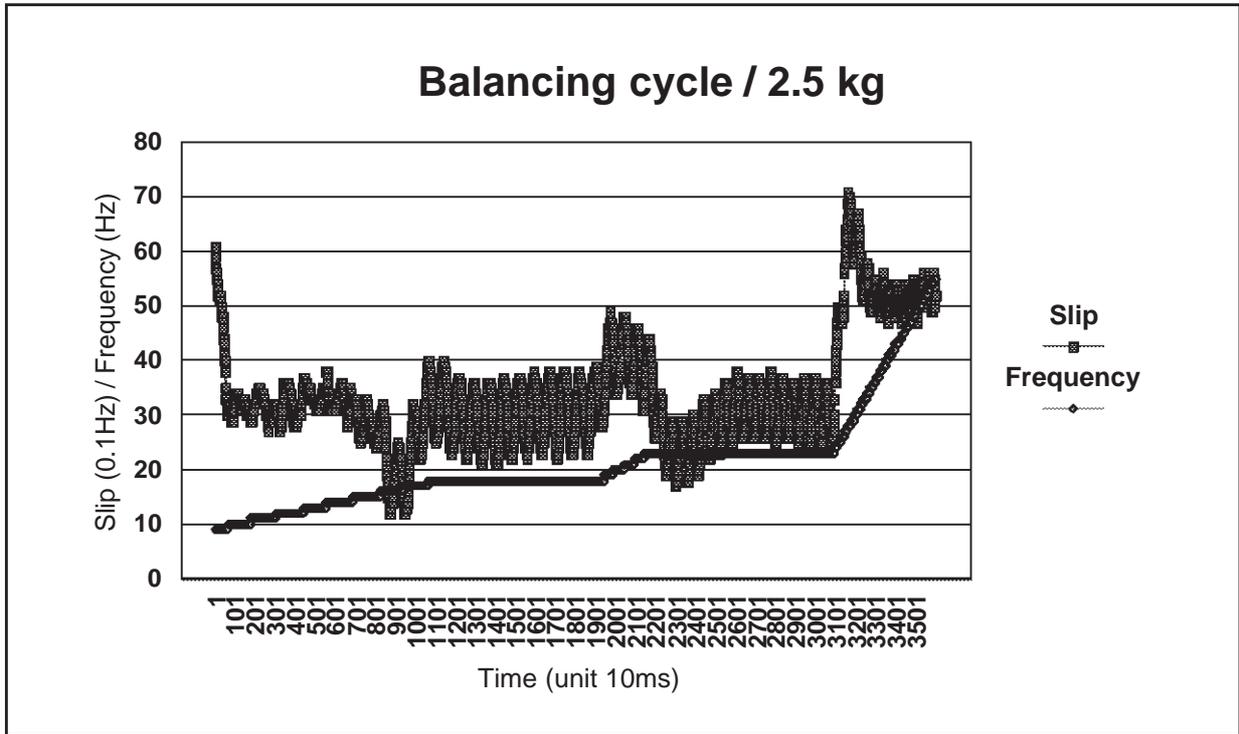
**Figure 4. System (motor + drive) efficiency at very low speed (550 r.p.m. rotor)**



Washing at 550RPM
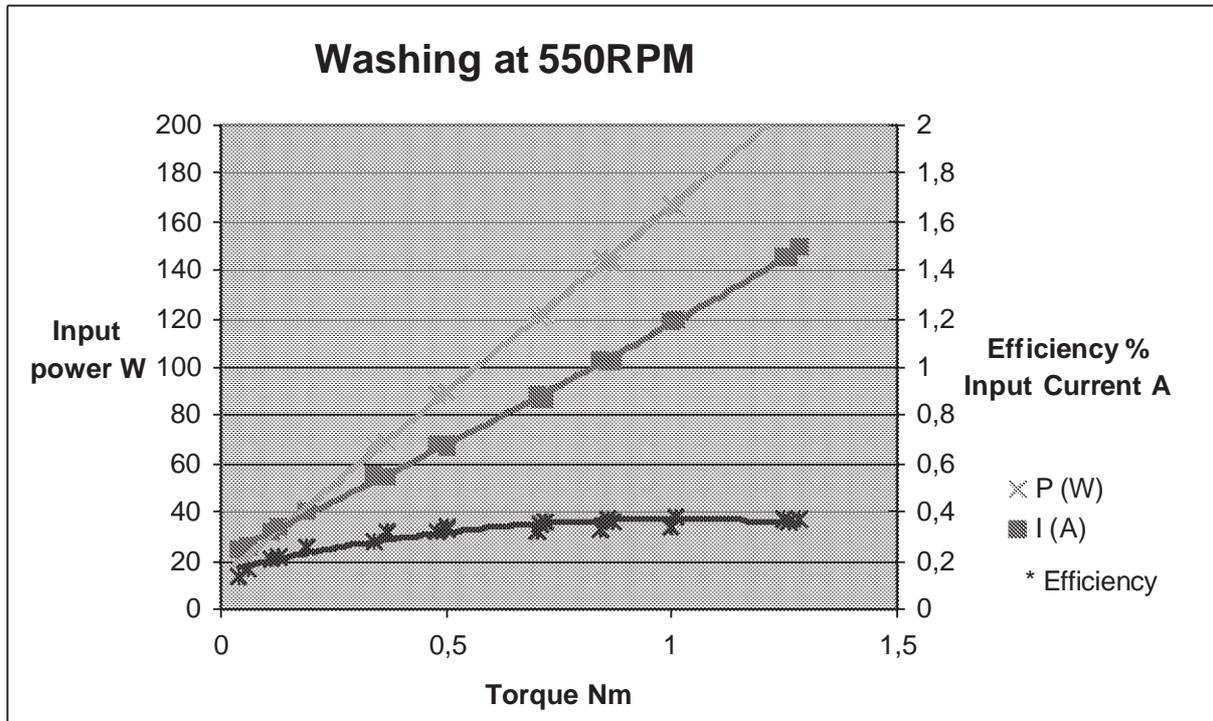
**Table 1. System Power consumption benchmark between brush Universal motor and brushless AC motor solutions.**

| (Motor + drive total consumption) | Brush Universal Motor W | Brushless Induction Motor W |
|---|---|---|
| 5Kg cotton washing process | 125 | 51 |
| 2.5kg cotton washing process | 210 | 80 |
| 2.5kg Terry clothes washing process | 250 | 150 |
| 1600 rpm spinning process | 750 | 650 |

**Table 2. System (motor + drive) efficiency at high speed**

| Motor speed r.p.m | Loading torque N.m | Input power W | Efficiency % |
|---|---|---|---|
| 16 600 | 0.19 | 440 | 75 |
| 16 600 | 0.24 | 550 | 76 |
| 16 600 | 0.29 | 650 | 78 |

**Figure 5. Power control linearity**
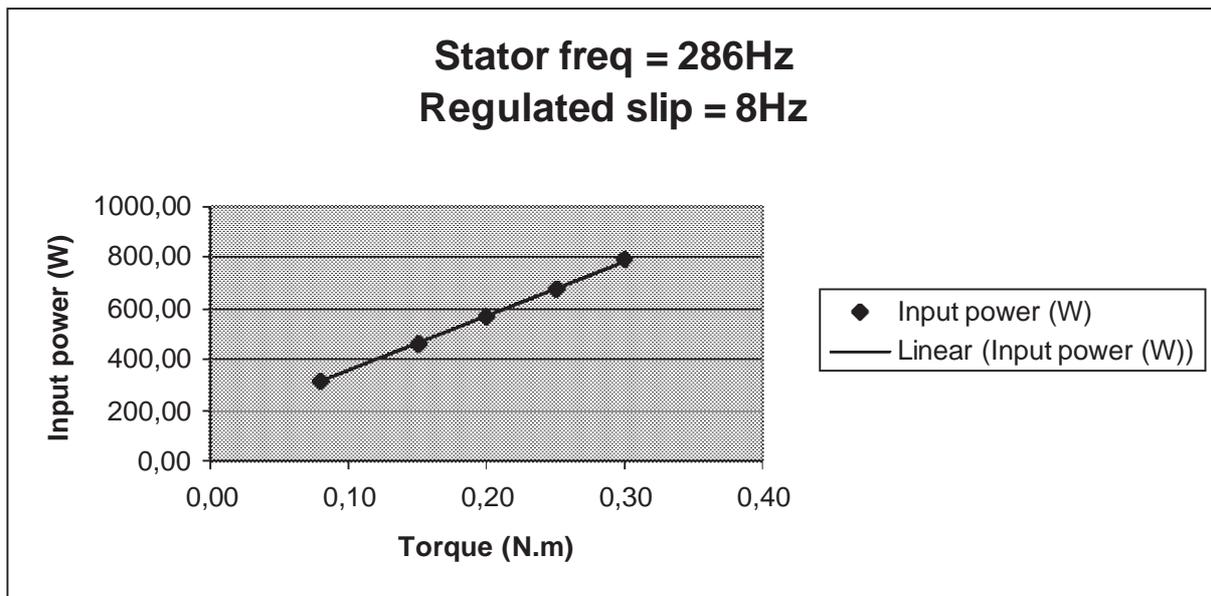
## Figure 6. Conduced noise with optimum Gate drive impedance
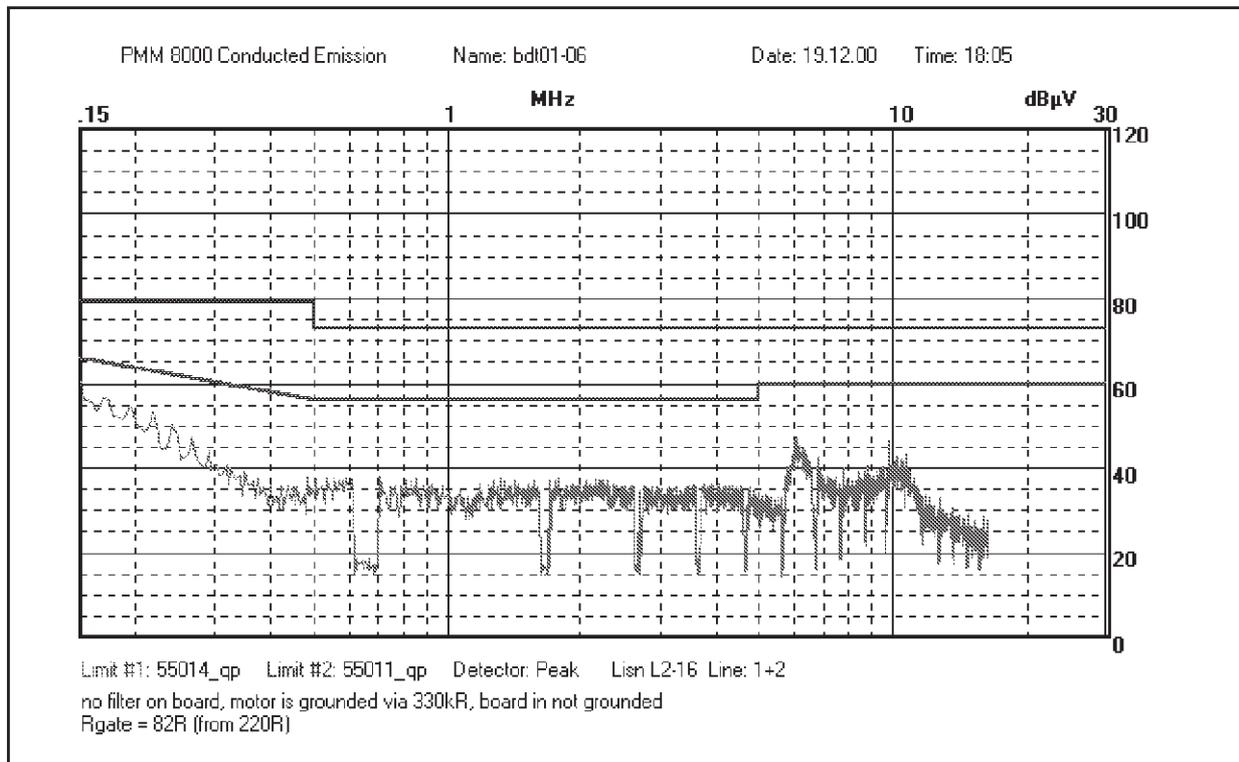
## APPENDIX: MOTOR CHARACTERISTICS
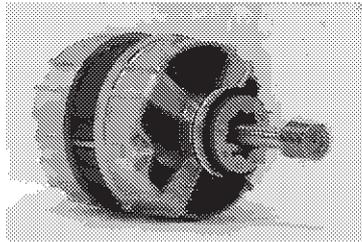


**MANUFACTURER:**

SELNI - NEVERS - FRANCE

**MOTOR:**

AHV 2-42-

**MAIN CHARACTERISTICS:**

MOTOR for WASHING MACHINES

Phase to phase voltage: 0 to 190 V or 0 to 250V

| | |
|---|---|
| Frequency (F): | 0 to 340 Hz |
| Insulation Class: | F |
| Geometry: | drawing 10102 |
| Speed ratio: | 10 to 16 |
| W.M Speed: | 0 to 1800 RPM |

**SPECIAL CHARACTERISTICS:**

| | |
|---|---|
| Stack Thickness: | 42 mm |
| Stator ref: | drawing 10230 |
| Stator lamination ref: | 21760 (24 slots) |
| Winding: | 2 poles, embedded, real poles |
| | R= 3,5 $\Omega \pm$ 5% ph to ph. at 23°C |

Without thermal protector

| | |
|---|---|
| Rotor ref: | drawing 10207T01 |
| Rotor lamination ref: | 27525 (28 slots) |
| Tacho Generator: | Electromagnet T 31 (2*8 poles) |
| Optimum slip: | From 3 Hz at low Frequencies to 8 HZ at high Frequencies |
| Maximum Torque: | 2 to 3 Nm at low speed |
| Maximal slip: | For F $\leq$ 5 Hz$\Longrightarrow$5 Hz |
| | 13 Hz$\Longrightarrow$5 Hz     25 Hz$\Longrightarrow$16 Hz |
| | 200 Hz$\Longrightarrow$28 Hz    340 Hz$\Longrightarrow$35 Hz |