Design and characteristics of a high-precision chopper wheel motor driver

Xi Bin Gu and Ying Guo
Department of Chemistry, University of Hawaii at Manoa, Honolulu, Hawaii 96822

Henry Chan
Department of Chemistry, University of California at Berkeley, Berkeley, California 94720

Ed Kawamura and Ralf I. Kaiser
Department of Chemistry, University of Hawaii at Manoa, Honolulu, Hawaii 96822

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The circuit diagram and design principles of a high-stability chopper wheel motor driver are presented. Experimental results show that this unit can be interfaced to molecular-beam machines to generate supersonic beams with extremely stable root-mean-square and peak velocities fluctuating on a day-to-day basis by less than 0.2%. © *2005 American Institute of Physics.*
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The crossed molecular beams technique represents the most versatile approach in the elucidation of the energetics and chemical dynamics of elementary reactions.[1] In contrast to bulk experiments, where reactants are mixed, the main advantage of a crossed-beams approach is the capability to form the reactants in separate, supersonic beams. In principle, both reactant beams can be prepared in well-defined quantum states before they cross at a specific collision energy under single collision conditions. The species of each beam are made to collide only with the molecules of the other beam, and the products formed fly undisturbed toward the detector. These features provide an unprecedented approach to observe the consequences of a single collision event, preventing secondary collisions and wall effects. Crossed-beams experiments can also help to identify those intermediates involved and provide reaction products as well as differential cross sections.[2]

The generation of supersonic reactant beams of sufficiently high concentration to guarantee a detectable quantity of the final reaction products is essential. Also, to derive collision-energy-dependent reaction mechanisms and chemical dynamics, the chemical composition and the velocity distributions of the supersonic beam must be constant during the experiments.[3] This is of particular importance if experiments are carried out utilizing pulsed molecular beams. Here, the velocity of each part of the pulse is—in strong contrast to continuous beams—distinct.[4] Also, in the case of laser-based ablation sources to generate, for instance, atomic carbon,[5] dicarbon, and tricarbon,[6] as well as cyano radicals,[7] the chemical composition of the supersonic beam can differ dramatically—electronically and/or vibrationally species prevail in the predominantly faster and hence less cooled parts of the beam. To select a reactant beam of a well-defined chemical composition and velocity distribution, fast-rotating chopper wheels are often utilized. Typically, mechanical choppers consist of a slotted disk that is interfaced to a motor and a driver circuit.[8] The stability of the motor driver dictates the beam characteristics (peak velocity, velocity spread, chemical composition, intensity) and also limits the day-to-day reproducibility of these parameters. Therefore, to minimize any fluctuations on the velocity and chemical composition of pulsed beams, the driver circuit has to be extremely stable. In this article, we present the design and characteristics of a novel, high-precision chopper wheel motor driver.

The chopper wheel motor driver has been designed to operate a 75A1004-2 Globe Motor in the frequency range from 50 to 400 Hz—a typical unit operated in various crossed molecular beams and photodissociation machines worldwide.[1,2] The circuit of the three-phase motor driver is shown in Fig. 1. The main frequency source is a Novatech DDS8m synthesizer. Its frequency output is based on transistor-transistor logic (TTL) and can be adjusted from 10 kHz to 100 MHz in 1 μHz steps; this system is accurate to ±1 ppm at 10–40 °C holding a long-term stability of ±1 ppm per year. The controls circuit has been designed using a Zilog microcontroller kit. The front panel switches for the frequency adjustment are read by the microcontroller; the new base frequency is calculated and the command is sent to the DDS8m through the RS232 serial interface to change the base frequency; hereafter, the new frequency is displayed on the front panel LCD through a digital interface. This base frequency is fed to the three-phase generation board; each of the three phases is generated by a direct digital synthesizer. Here, the base frequency is fed into a 10–bit binary counter; the parallel output of the counter is fed into three EPROMs representing three look-up tables. The tables contain the digitized values of a full sine wave cycle. Each point is 8 bits wide; each table is 1080 points deep and phase-shifted 120 degrees from each other. The outputs of the tables are fed into three digital-to-analog converters, thus generating three phases to operate the motor. The reference-generating board monitors the base frequency and will shut down the reference in case of base frequency failure. The actual voltage amplitude can be adjusted by a 10–turn potentiometer.

The power driver boards are powered by a ±28 V supply. To protect the motor in case of power fluctuations, this unit holds a relay circuit to cut off both the + and − voltage supply if either one fails. All remaining logic and analog

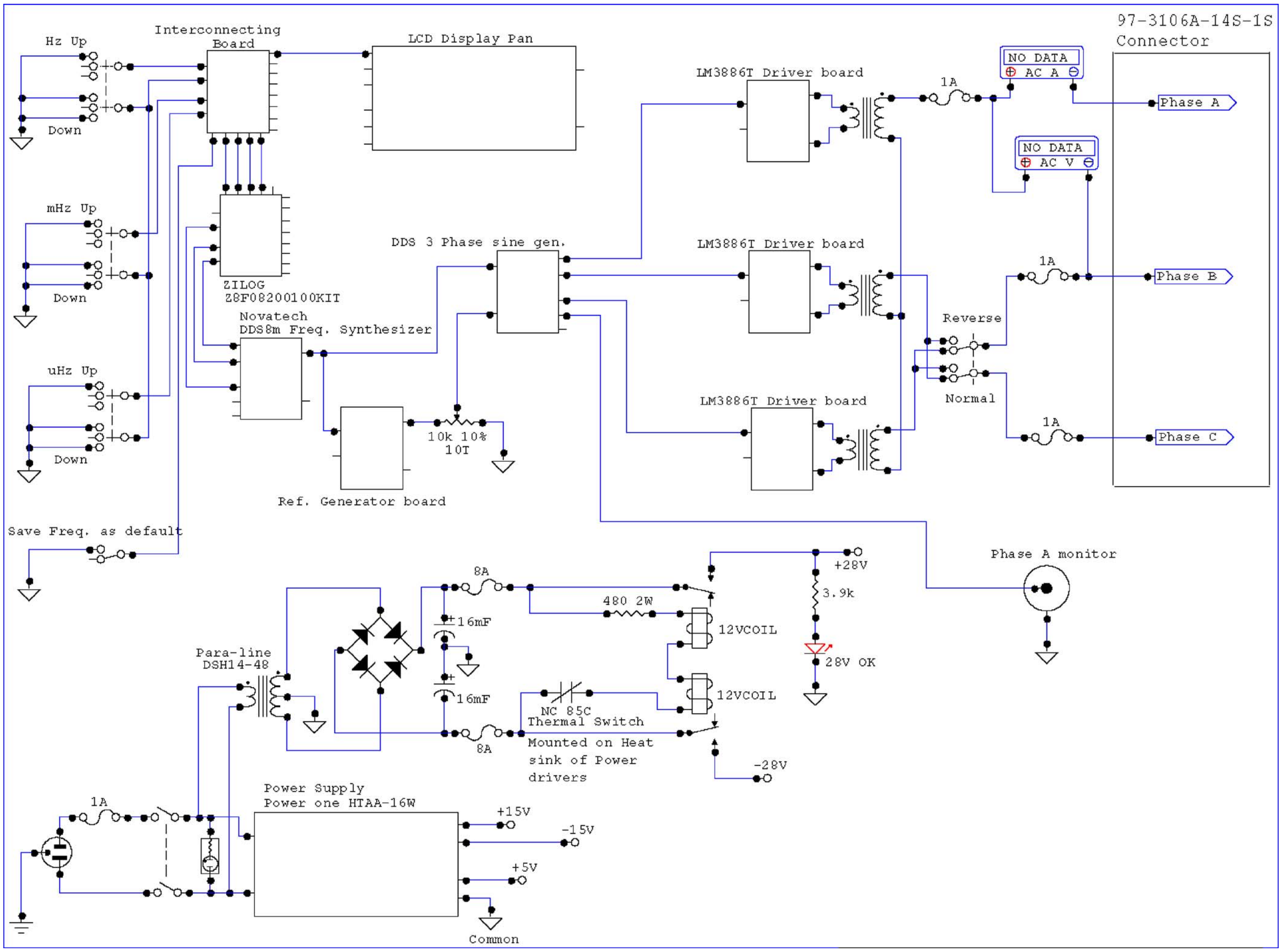

FIG. 1. Block diagram of the motor driver.

circuits are powered by a Power One HTAA-16W triple supply. Note that the power drive stage uses three 68W audio amplifiers LM3886T. The output of each power stage is fed into the low-voltage side of three power transformers (56 V; 1 A). The high-voltage side of the transformer drives the motor. Each of the power drivers has an over temperature switch mounted on the heat sink so that the ±28 V supply can be shut down if the temperature increases beyond 40 °C.

Compared to an older design of the motor driver,[7] the new unit has a higher resolution both in terms of frequency and the wave form. Whereas the previous unit incorporates four steps in the amplitude and eight steps in the phase resolution for the sine function, the present driver has 256 steps in amplitude and 1040 steps in the phase resolution. This in turn provides a more realistic sine wave simulation. A second upgrading is the frequency resolution. Here, the old design is adjustable in 1 mHz steps, whereas the new unit is adjustable in 1 μHz steps. Finally, the user interface also advanced with the LCD display and a storage capability of a default driver frequency.

To test the performance of the new driver, we coupled the unit to a 75A1004-2 Globe Motor which in turn is interfaced to a chopper wheel of 17.0 cm diameter with four 8-mm-long and 0.76-mm-wide slots located 90° apart. The chopper wheel frequency is monitored via the TTL signal of an infrared diode (Newark Electronics; OPB960) mounted to the top of the motor support frame which is fed into a frequency counter (Fluke PM6669). This signal provides the time zero for the experiment and can be fed into a frequency divider, pulse generator, multichannel scaler, and/or pulsed valve driver. To characterize the long-term stability of the driver unit and the chopper wheel assembly, this system was placed in a crossed molecular beams machine described in Ref. 9 in detail; the chopper wheel was operated at frequencies between 100 and 240 Hz; typical stabilization times of the chopper wheel are about 30 min. Time-of-flight spectra of various noble gases in pulsed and continuous beams were recorded, and the velocities as well as the speed ratio derived (Table I).

These data suggest that the enhanced resolutions of the amplitude and the phase of the sine wave translate into an improved stability of the motor driver, thus providing narrower temporal duration of the selected pulsed beam (reduction from ±0.1 to 0.01 μs) and also fewer fluctuations in their peak velocities (reduction from ±5% to less than ±1% in the case of ablated beams).[7] The latter aspect is of particular importance if pulsed supersonic molecular beams are utilized since the delay time between the photodiode and the pulsed valve dictates which part of the supersonic pulse will be selected by the chopper wheel. Recall that in strong con-

TABLE I. Characterization and stabilities of the root-mean-square velocities (V_{rms}) and speed ratios (S) of various continuous (cw) and pulsed (PV) supersonic beams; in the case of polyatomic molecules, the peak velocity (V_{peak}) is given. The speed ratio can be expressed as $1.65/(\Delta v/v)$ with the mean velocity of the beam (v) and the corresponding velocity spread Δv (Ref. 13).

Gas	Backing pressure (Torr)	v_{rms}/v_{peak} (ms^{-1})	S
He (cw)[a]	900	1748±1	20±1
Ne (cw)[a]	700	783±1	25±1
Ar (cw)[a]	400	557±1	30±1
Kr (cw)[a]	300	382±1	19±1
He (PV)	3040	1947±2	25±1
C_2H_2 (PV)	550	902±2	16±1
C_2H_4 (PV)	550	896±2	16±1
C_2/He (PV)[b]	3040	1673±4	4.1±0.2

[a]Depending on source geometry and nozzle-skimmer distance.
[b]Ablation source.

trast to continuous beams, each section of a pulsed supersonic beam holds a distinct peak velocity. Likewise, faster parts of the pulsed beam may contain electronically $[C(^1D);{}^{10}C_2(A^1\Sigma_g^+)^{11}]$ and highly vibrationally excited species $[CN(X^2\Sigma^+);\ v=0-4]$ (Ref. 7) generated in supersonic, laser ablation sources.[10–12] This is of paramount importance if crossed-beams reactions have to be carried out since the electronically/vibrationally excited species can have distinct reaction dynamics compared to their ground-state counterparts. Therefore, a stable chopper wheel driver guarantees also a constant composition (ground state versus excited reactant species) of the supersonic beam. Even in continuous beams, a steady chopper wheel driver is crucial to provide a constant dead time of the photodiode attached to the chopper wheel. Summarized, the enhanced stability of the motor driver results in fewer fluctuations in the peak velocity of continuous and pulsed supersonic beams and ensures also a steady composition of supersonic reactant beam—in particular if they are generated, for instance, in carbon and boron laser ablation sources.

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