General Application of Printed Motors

The Printed Motor was originally conceived in the early 1950's as a low cost DC or universal machine which, in virtue of its disc shaped laminated armature, could be mass-produced in high volume. However, the introduction of this type of motor by the S.E.A. Company in France demonstrated that the machine possessed several properties which defined the essential characteristics of an ideal servo motor.

These properties are:

1. High torque combined with low armature inertia.
2. Very short mechanical and negligible electrical time constants.
3. Large number of commutator bars and "slots", resulting in extremely smooth torque output with no "cogging."
4. Near-perfect commutation even under high pulse current operating conditions.
5. Linear speed-torque characteristic. (Expressed in servo terms, a non-varying transfer function over the entire operation range of the motor).
6. Complete freedom from distortion and/or demagnetization of the permanent field, even during heavy overload conditions.

Two other factors were in favor of the Printed Motor at this time. AC servos, in spite of their sophistication and advanced design exhibit certain severe limitations. Wide speed ranges are difficult to achieve and AC motors do not inherently possess many of the desirable characteristics of a DC servo motor. Thus, the availability of a high performance DC servo became of very special interest to designers working in such diverse fields as precision tape recorders and tracker antenna drives. A second factor of some considerable importance in the rapid development of high response DC servos was the arrival of relatively low cost semi-conductor rectifiers (SCR.'s) and power transistors. For example, DC-coupled servo power amplifiers capable of delivering pulse powers on the order of 1 KW are now readily available, while SCR. Power-drive amplifiers are for controlling 1 to 50 HP DC servos. SCR. controllers for industrial fractional HP drives offer wide speed control and are adaptable to printed motors with only minor modification.

Basic Considerations

It is easy to classify servomotor types together with their associated method of contro. A study of these types immediately reveals certain underlying principles for specifying Printed Motors.

Probably the most frequently-occurring situation in which a Printed Motor can be fitted is one where the shaft output speed is required to be variable (either continuously or in discrete steps) and where smooth torque output is demeaned. In many instances, neither shaft out put speed (once set) nor the smoothness of the torque can be impaired, even in the presence of large variations of disturbance in load torque. The disc armature motor satisfies the requirements of each application by virtue of special characteristics which are not normally attainable in other motor designs.

The following material gives a brief outline of the major applications areas which have been investigated, and the reasons why printed motors were specified.

Application Types - SERVOS

There are currently several areas in which precision PM servos are being employed. Five other application types are non-servos and employ low cost ferrite magnet structures with mechanically-fabricated armatures.

Servo applications are considered in detail since this is the area in which greater applications engineering effort is normally required.

Magnetic and Paper Tape Handling

Magnetic and paper tape capstan drive servos are an obvious “natural” application for printed motors. Analog magnetic tape drives require very constant speed control and capability of operation over a wide speed range, with typically better than ±0.1 per cent velocity error or “flutter”. Tape speeds of 60, 30, 15, 7-1/2, 3-3/4, 1-7/8 in-per-second are common in the instrumentation field, while video and audio tape transport capstans may be driven at only 2 speeds (15” and 7-1/2” per-second).

The most accurate method yet devised for controlling capstan speed is a synchronous phase-lock, such as PMI-Photocircuits’ S-1. Speed Control by this type of servo is “absolute” in the sense that the servos electronics introduce zero error in the drive Errors in capstan peripheral velocity are entirely due to external torque disturbances, mechanical error, and bearing noise. A well-designed phase-lock servo largely eliminates the effects of external torque fluctuations, leaving the overall capstan speed accuracy of function of the reference oscillator and bearings. In this context, all types of PMI-Photocircuits’ Motors are available with digital optical or magnetic tachometers. For precision systems, these units are constructed with extremely close shaft tolerances, ABEC Class VII bearings and double pick-off whereby significant tachometer eccentricity and shaft run out errors are avoided.

Digital Magnetic Tape Capstan SERVO

The requirements of a good direct digital capstan servo motor are similar to those specified for instrumentation and video tape applications, except that speed control is normally not as critical (typically ±4 per cent), and the speed range seldom exceeds a 2:1 ratio in any given system. However, there is one very important difference. Namely, the paramount need to start and stop the tape very rapidly. For example, in a 75 ins. per second (i.p.s.) transport, the capstan must be accelerated to full speed in less than .005 second. A typical 75 i.p.s. tape transport specification calls for tape reversal (full speed c/w to full speed cc/w) in .010 sec. If the minimum block of data is to be read or written, it may account for a .006 sec. run time. The maximum number of start-stop cycles per second which the capstan must execute is 1/0.016=67 c.p.s. This is referred to as the start-stop repletion rate and is of considerable importance when considering the power dissipation of the capstan servo motor.

Mention should also be made of the so-called Incrementer tape drive where the capstan is required to advance the tape in small discrete steps of (typically) .005" and at a rate which may be as high as 300 steps per second (See AFIPS (JSCC 1966) Proceeding; Authors: R.P. Burr, J. Rheinhold, and R.K. Andres, Title: *A New Development in the Transmission, Storage and Conversion of Digital Data*.)

As with digital tape handling mechanisms, the very low inertia and high acceleration capabilities of the printed motor provide the high performance and reliability inherently required for systems of this type.

Paper tape reader capstan servos employ PMI drive motors for high performance and reliably in all modes of operation. There is one special feature of the Printed Motor capstan which has not been mentioned, the capability with this type of servo to operate in a "synchronous" slewing mode. For very fast reading of paper tape, this method of tape drive adds considerably to the overall flexibility of the tape system.

TAPE SPOOLERS

For every capstan servo motor there are inevitably two reel servos (See CRC Engineering Memorandum EM32 for a full discussion of the reel servo application). The tape must be unwound and wound. The performance of the reel servo is largely determined by the overall tape transport specification. In fact, neither the capstan drive nor the reel drive motors are considered in isolation. The three motors are essential parts of an integrated system.

High performance tape handling mechanisms generally employ proportional control. The reel servo acceleration torque is a proportional function of and derived from the output of some position sensor. For example, a paper tape reader employs a pair of tape loop sensing arms, the position of each one controlling its associated reel motor armature current in both the required direction and magnitude.

High speed magnetic tape systems use vacuum columns into which a loop or reservoir of tape is drawn. Due to the relatively large inertia of its load, the spool motor cannot be expected to accelerate the tape at the same rate as the very low inertia capstan. Even when relieved of this otherwise impossible task by isolating the vacuum columns, the reel servo is still called upon to perform very rapid excursions of acceleration torque between the high positive and negative values (typically ±500 to 1000 oz.-in).

In medium speed digital equipment, printed amateur motors such as the U16M4H posses considerable merit in this application because of their ability to handle large instantaneous pulse torques in either direction with the deterioration in commutation, a common cause of reliability problems associated with many conventional DC motors.

Although the reel servo requirement of instrumentation and video tape recorders seem to be less exacting, this is far from the case in practice. PMI motors are currently used as reel motor by several manufactures of analog type tape recoders, chiefly because of the extremely smooth and trouble free perfomance which they offer.

There is a very similar application for Printed Motor spooler servos in film transports, for example, in high speed photo typesetting equipments. Servo bandwidths are necessarily low because of the high load inertias and motors used in this application are generally operated in a medium to high gain position servo with bi-directional SCR power drive amplifiers.

Instrument Servos

A servo, frequently referred to as a null-balance position type (or Type “1” servo), is found in X-Y plotters, strip chart recorders and as multipliers in analog compution devices. These servos are usually designed around the two-phase AC servo motor which, for many years has held a demonstrable superiority in this area. In addition, AC Servo “packages” are available that satisfy a majority of applications. Smooth torque output is no advantage with the residual 60 or 400 cps of friction and the resultant dead-band. Small size AC servo parable DC motors with peak torque availability, functions well. It is cheap, and relatively reliable.

In recent years, increasing interest has been shown in the potentially improved performance offered by the printed motor, especially for such mechanisms as the high inertial X-Y plotter cross arm. There is also considerable demand for improved response in some ctart recorders, Specifically, the 10” pen travel is the highest response recorder currently available and takes ¼ second for stop-to-stop. Thus, using the instrument required to record a transient in which the dominant frequency is greater than 2 c.p.s., considerable errors have been found in the recorded data. In many systems, this effect is mitigated by making FM magnetic tape recordings and playing back at one tenth speed or some other proportionately delayed play-back process. Evidently, there is a need for potentiometer recorders with a 10 to 20 c.p.s. position bandwidth; and the U series motors developed by Photocircuits, should find application in this general area high response analog instrumentation position servos.

Computer Input-Output Equipment

A large number of Printed Motor Applications are found in computer input-output equipment, notably high-speed multi-colum line printers, card readers and disc files. Practically every modern digital computer is severely limited in the time required to process a problem by the relatively low speed at which data can be fed into and out of memory equipment via mechanical or electro-mechanical data storage devices. For example, card readers typically operate at a data transfer rate of 10.000 bits per sec. The computer's central processor or arithmetic unit can probably operate on data being transferred to it from storage on the order of ten times this rate.

The 75 i.p.s. magnetic tape transport transfers data at 75 x 800 = 60,000 c.p.s. per-channel for 800 bits-per-inch of tape.

There is constant pressure on peripheral equipment designers to maintain data transfer rates as high as possible. There is no better example of this than the muli-column line printer. Specification for printing rates have risen steadily for the past five years from 8 lines per sec. To 16, 25, 33; and even 50 lines per sec. now being achieved in experimental units.

The Printed Motor is ideally suited to the paper tractor drive servo application because of the perfect inertial match between motor and load, the ability of the Printed Motor to deliver the necessary high acceleration torque, and the high reliability of direct-coupling without the use of intermittent motion mechanical elements (clutch and brake systems).

A very rapidly growing category of motor application is seen as the intermittent motor type servo, commonly referred to as the “incrementer”. In this form of servo, a type “0” regulator, instead of being referenced to a fixed or programmed DC level, is switched alternately as required between two levels; a “1” or GO level and a “0” or STOP level. In a practical system, the two reference levels are obtained from a bi-stable circuit or flip-flop triggered with the GO condition by an external command pulse. At the end of a predetermined motion displacement, the flip-flop is reset to the STOP level by a pulse derived from a position sensor mechanically-coupled to the motor drive shaft.

An important parameter that must be taken into account early in the design of high speed incremented equipment, is the power dissipation rating of the selected motor. A repetitive start-stop motion produces relatively little useful output, in the sense that as little as 10% of the input power may be required to overcome system friction. The remaining 90% of the input power achieves only acceleration and deceleration of the mechanism. Consequently, 90% of the input power to the motor is dissipated as heat of the armature, or “loss watts.” To compound this problem, the most rapid start-stop condition (line-by line single column word operation) may not represent the “worst case”. Frequently, the printer prints one line and (as rapidly as possible) skips several more. If checks are to be printed at a rate approaching the maximum system capability, the drive servo motor must dissipate many times the power consumed in the line-by-line mode.

There is nothing unique about this situation. Printed Motors operate with very large overload currents. Like all electric motors, they do not continue to operate under conditions of severe over-heating. It is important in "power limited" incremented applications to provide air cooling of the drive motors either by efficient blown heat sinking, internal force cooling, or a combination of the two.

Machine Tool Drive Servos (and Antenna Drives)

A significant applications area for Printed armature Motors exists within the machine tool industry. The requirements for a good servo motor are:

a) Power output in the 1/2 HP to 10 HP range.

b) Mechanical time constant in the 0.005 to 0.025 second range-nearer the lower figure for very high performance system.

c) Very smooth torque output, especially at low speeds.

d) In combination with a well designed servo power amplifier, the motor must be capable of full torque (in both directions) down to and at zero speed.

e) High reliability and ease of maintenance.

The electric drive servo competed more than favorable with hydraulic drives until the "conventional" method of obtaining broad-band servo performance in large machine actuators.

With the introduction of Integral HP Motors, PMI now has a full range of competitively priced DC servos motors being employed in a large number of numerical control applications such as spindle drives, lead screw driven slides on turret lathes, milling machines, finishing grinders and contouring machinery. Examples of point-to-point applications using Printed Motors include printed circuit drilling machines (for X-Y co-ordinate drives), electronic assembly or component insertion machines and printed circuit multilayer drafting machines.

A closely-related application is found in small and medium-sized tracker antenna drives and stable platform servos.

Machine tools and antenna drives have the following common features:

Ï The system frequency response is generally high (from 5 to 50 c.p.s.).
Ï The system accuracy is such that a high gain positioning servo is essential.
Ï The motors must be capable of producing high acceleration.
Ï Stall torque "per dollar" and per lb. weight.

The wider use of PMI motors was delayed in this application due in large measure to the non-availability of high power drive servo amplifiers. Broad band SCR power drive amplifiers such as the "Sciakdyne" enabled designers to realize the potentially large improvement in overall system performance possible with electric servos. Other high performance SCR type amplifiers have been developed both by the motor manufacturers as well as users.

Web Drives

An important servo classification is the large size "tape handler" in which the "tape", a web of film or synthetic material or filament yarn, is processed in continuous lengths. Speeds of web movement are generally low (from 1 thru 120 ft.-per-minute) and the motor shaft requires that several drive motors operate at identical speeds. Moreover, the speed, once set, must be accurately maintained (typically better than 0.1%). This application is ideally suited for large Printed Motors. Control is by means of S-1 type phase-lock servos combined with high current drive amplifiers. In some systems, several drive stations (located at different points in the process installation) may be accurately synchronized.

Aero-Space

Printed motors have been specified for use in a limited number of ground support type applications, such as missile check-out and flight simulator equipment. Precision motors are supplied to readily meet Air Force ground support environmental requirements, either as components in their own right or as sub assemblies. A printed motor incremental servo was designed into the flight navigation and control system of a missile in which a very high speed, programmed, intermittent-motion performance was required. This was an important development that resulted in similar airborne applications elsewhere. For security reasons, no published performance data is available. PMI-Photo-circuits Amplifications Engineering can, advise potential users unclassified general information with regard to the programs in which PMI motors are being employed, such as test and design specifications and copies of test reports.

Application Types - Non-Servo

The early mass production of the Printed Armature motor was realized with the advent of ferrite magnets and armatures fabricated from die stamped and welded copper laminations (See PMI Brochure, *Ferrite DC Motors for Commercial and Industrial Applications*). It was evident from a study of the construction features that these motors could be inexpensively produced in volume. Performance does not compare with the servo line motors, due to the much weaker magnetic field obtainable from the ferrite materials. However, these magnets posses both high retentively and coercive force, resulting in short axial length an eliminating the need for magnet charging after assembly.

(A number of armature configurations were developed using this new technology, notably the 4-layer 8 and 10 pole wave and lap windings. These armatures offer considerable advantage in motor sensitivity and efficiency when used in the high flux normally available with alnico magnets).

Automotive

12 VDC motors with performance characteristics of the Printed Armature Motor offer considerable potential as actuators and blower motors in the automotive accessory field. Typical of these applications are window winders currently manufactured under license by The Dura Corporation and blower motors developed by another major supplier for the automotive industry. High starting torque and capability of the motor to withstand high short duration overloading combined with an ideal pancake geometry and low terminal voltage, make this type of motor a natural choice for automotive use. Antenna retractors, battery-operated lifting jacks, windshield wipers and seat adjusting actuators are all applications for this type of DC motor.

Business Machines

Typewriters, electromechanical desk calculators and office machines all require electrically-driven sources of DC mechanical power. Portable, rechargeable, battery-operated machines appear to be a "natural" application. Standardization might dictate the use of similar motors in static systems.

Dictating machine tape or disc drives can use ferrite motors in combination with some fairly elementary form of speed control. The potential use of motor components (e.g., magnets and armature structures) that the manufacturer can integrate directly into his product is undoubtedly large.

Sound Film Projectors

This is an interesting, high-volume application for small ferrite motors. The conventional motion picture film transport, while highly-developed and essentially reliable, leaves much to be desired. Intermittent motion gate and sprocket drivers are noisy, cause considerable film wear and are uneconomical in light transmission. Supply and take up reels, as well as sprockets and sound capstans are usually mechanically-linked to a single motor drive by belts and slipping clutches.

Considerable improvement in performance can be achieved by the use of ferrite motor drives. The "5-motor" film and magnetic tape transport overcomes virtually all the mechanical problems. Continuous film motor, without the need to bring the film to a standstill, was achieved uing special synchronized rotating prisms. Both sound and picture quality were improved with significant reduction in image jitter (random displacements between successive frames) and flutter due to departure from the true speed at the sound head.

The same principles apply to small, portable, battery-driven video recorder/reproducer systems. A significant contribution to the state of the art was made possible by the use of inexpensive disc armature motors in multi-motor drive configuration.

TABLE 1
APPLICATIONS OF PRINTED FRACTIONAL HP,
INTEGRAL HP, & FERRITE MOTORS

APPLICATION INDUSTRY	MOTOR MODEL NO.	TYPE OF CONTROL	SPECIAL CHARACTERISTICS
1. Magnetic and Paper Tape Transports (Digital and Analog)	U9M4 U9M4H U9M4HA 10C12	Capstan DC Amp. and S-1	Low mechanical time constant; high acceleration; extremely rigid mechanical specifications; smooth torque; absence of cogging. Ideal motor for use with phase lock control.
2. Tape Spoolers (Magnetic and Paper)	U12M4H U16M4 U16M4H	Position SCR or DC Amp.	High torque; convenient geometry, will handle repetitive pulse operation.
3. Instrument Servos, X-Y Plotters and Chart Recorders	U9M4 U9M4F U12M4F	DC Position DC Amp. Digital or Analog	High gain, very accurate infinite resolution position response. High acceleration; usually costs more than AC servos, but U-line motors (with ferrite magnets) offer price competition.
4. Computer Input-Output Equipment Line Printers Card Readers Disc File head locators	U9M4H U12M4 U12M4H 10C12	Intermittent Motion Servos DC Amp Coupled Power Servo	Very fast incremental performance. Line print to 50 lines per sec. Card readers to 20 cards per second. Disc file head movements in milliseconds
5. Antenna Drives Machine Tool N/C Drafting Machines	U16M4 U16M4H	Digital or Analog Position Servo. 360 cps, 3 phase, SCR 400 cps, full wave SCR Sciakydyne	Low inertia; high acceleration; very smooth high torque capability especially at low speed, accurate control down to zero speed at full torque. Precision motors designed to MIL requirements and for rugged industrial use, prices competitive with hydraulic systems.
6. Web Drives Film Paper processing Photo-composing machines Filament winders	U16M4 U16M4H	Const. Speed S-1 type or Sciakydyne	Very high torque precision speed control; accurate "instantaneous" speed and position control. Wide speed range and excellent performance at very low speeds e.g. less than 10 rpm in special systems.
6A. Other specialized industrial drives; Nuclear Reactor Control; Paper cutting and edge guide servos. Weaving and Knitting machines. Valve actuators.	U16M4 U16M4H and larger sizes	Various, mainly SCR	High temperature operation with U-Line. Low pressure operation with special brushes. Ability to perform well in high vibration and shock ambients.
7. Aerospace. Ground support.	U-Line MIL-SPEC	Various, Direct coupled DC	U-Line qualifies to MIL-SPEC in several MIL programs
8. Automotive window lifts Heat blowers Windshield wipers	Ferrite	Battery	DC 12V Source, Cheap, Flat Geometry. High stall torque.
9. Business Machines Electric Typewriters Card Sorters and desk calculators, etc.	Ferrite	SCR Drive	Variable speed available if required or speed changing possible without gears. Easy of assy. Into frame of machine. Inexpensive
10. Sound Film Projectors (& automatic slide projectors)	Ferrite	Simple SCR or DC Amp.	Multiple Motor Drives overcome many mechanical problems in conventional systems.
11. Home Appliances, Blender/Mixers, Washers, Sink, Floor Waxers, etd.	Small Ferrite, <1/2 H.P.	Simple SCR Controllers	Variable speed with SCR drive. Flat geometry, high stall torque, ease of assy. Into frame of device, inexpensive
12. Traction, Golf carts, Lawn Mowers, light delivery vehicles	Large Ferrite >1/2 H.P.	Battery operation	Simplicity of control. Good starting torque; can be easily designed into machine frames

Home Appliances

Several designs for disc armature ferrite motorswere evaluated for mixer-blenders, garbage disposal units and other power-driven home appliances. The blender-mixer has multi-speed requirement that can only be met with universal motors by virtue of an expensive tradeoff in efficiency.

Electric Vehicles

Some consideration has been given to the use of larger ferrite magnet motors (up to 1 HP) in electrically driven vehicles, golf carts, light delivery trucks and electric (battery operated) lawn mowers. All depend upon two factors: a motor that is at least 75% efficient at speeds around 1000 to 2000 rpm and improved "volt-ampere per-lb. and per-dollar" rating of secondary (rechargeable) batteries.