Xerox's High Temperature, Increased Fluid Latitude, High Performance Print Head

David A. Tence, Xerox Corporation, Wilsonville, Oregon USA

Abstract

Inkjet printing is becoming widely used in areas beyond current document printing such as digital fabrication and industrial printing. Success in product development for different digital fabrication and industrial printing applications is greatly dependent on the fluids that are printed. Xerox has developed the M-series print head, which is an innovative stainless steel head capable of jetting a wide variety of fluids at both ambient and elevated temperatures. This head has been designed to have long life and high reliability. Also it has one of the highest fluidic outputs, per linear inch, of any print head in the market today. The goal of this paper is to give the reader some understanding of following for the M-series head. First it's mechanical and fluidic design, how the print head is constructed, its high performance operation, and its ability to jet fluids at a variety of temperatures. Second the paper discusses the heads unique ability for jet to jet calibration, key implementation guidelines, and its great reliability and robustness. Third the paper talks about current uses of the head and future variations that can enable more digital fabrication and industrial printing applications. This paper describes the value of the M-series print head and its usefulness in expanding the digital fabrication and industrial printing revolution.

Introduction

The application of using ink jet print heads for digital fabrication and industrial printing is just at the start of a technological expansion. The print head technology that has been originally developed for printing on paper, over the last several decades, is starting to fuel a digital fabrication and industrial printing revolution. It should not be surprising that this is happening, since effectively these print head devices are just are just micro-fluidic deposition machines. Current print heads are capable of jetting micro droplets on the order of picoliters, at high frequencies in the tens of kilohertz range. However due to the construction of these heads many of them are limited in the fluids they can print, as well as the volume they can deposit per linear inch.

Xerox has developed the M-series print head that is ideal for many high demand industrial applications. Its fluid latitude is greater than any print head on the market today. It can jet fluids at temperatures ranging from ambient to 140C . It will jet fluids such as water based inks, UV inks, wax based inks, and even acids. The materials that contact the fluids to be jetted are just stainless steel, gold, and Teflon. So as long as fluid has reasonable jetting fluid properties, and is compatible with those simple yet robust materials, they can be jetted thru the head. This advanced Xerox print head also has the capacity to jet, on a linear inch, more fluid than almost any print head on the market today. This makes it one of the highest performance print heads available.

This paper overviews the Xerox print head, describing its design, performance, implementation requirements, reliability, current industrial uses, and future variations.

Head Design

The innovative M-series Xerox print head is an industrial head that is ideal for needs which require a high deposition rate, wide fluid latitude, and robust operation over a variety of temperatures. The head itself is a piezoelectric print head shown in Figure (1), and consists of a jet stack, flex cable, and an electronic driver board. The jet stack contains the fluidic parts of the print head such as the ink delivery manifolds and individual jets. The flex cable makes the electrical connection to the piezoelectric drivers and contains a film heater for temperature control. The electronic driver board takes a serial stream of data and uses it to enable jets to fire. The driver board also has calibration capabilities and relays serial information from the head.

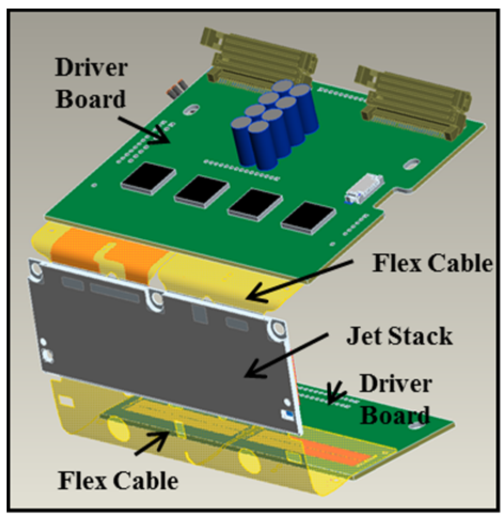

Figure 1. *Xerox M-series Print head.*

A good overview of the design of this head is outlined by Korol [1] in his 2008 NPI paper. However a more detailed description is put forth in this paper. The jet stack consists of 880 jets contained in an array width of 2.93 inches (74.5 mm). These jets are arranged in 16 different rows and can be laid out in multiple aperture arrangements that will allow for different printing modes. The different arrangements that are currently available are a 300 dpi mono printing arrangement, a 150 dpi two color printing arrangement, and a 75 dpi four color printing arrangement. However subsets of these arrangements are also possible as well. An example would be a 3 color head in which one color is 150 dpi while the remaining two colors are 75 dpi. To illustrate the aperture arrangement Figure (2) shows the aperture plate for the Mono M-series 300 dpi print head. One thing to note is that along the center line of the aperture plate is a concentration of holes not shown in the detail. These holes are not actually apertures for individual jets, but are vents to purge fluid from feed manifolds in the stack.

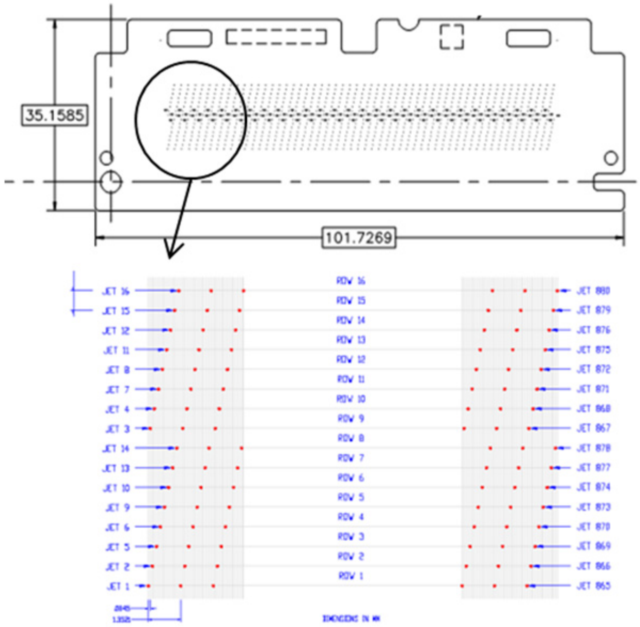

Figure 2. *300dpi Aperture Layout.*

The head is constructed of 16 stainless steel plates that are brazed together to form the jet stack. Of these plates 15 of them are chemically etched to form the fluidic channels within the stack. The 16th plate is an aperture plate that consists of 39.5 micron apertures, made by a proprietary process at Xerox. After the stack is brazed together an anti-wetting coating of Teflon is applied to the surface of the jet stack. This coating is important for head maintenance and reliable jetting performance. The only materials that jetting fluids come in contact with in the M-series print head are stainless steel, minor amounts of gold, and Teflon. This makes the head incredibly robust to a variety of fluids, as well as being constructed of materials that are fully approved of by the FDA.

When the steel part of the jet stack have been finished the piezoelectric transducers (PZT's), which have been diced into individual drivers, are glued to the back of the stack. This allows for the piezoelectric head to use a bending mode to generate the pressure pulse in the individual jets to eject droplets. The next step in building the print head is to attach the flex cable and make the electrical connection to each individual jet. This is done by using a B-staged epoxy for the flex attachment and silver epoxy to make the electrical connection. After these compounds are applied to the parts they are finally cured using heat and pressure. The final step in building the print head is to attach the electrical driver board. This is done by placing a z-axis tape in between the flex and electrical contacts on the head driver board. Again heat and pressure are applied to cure the material. The tape acts as both the mechanical and electrical connection between the parts.

The final stack itself is 4 inches in width (102 mm) and 1.5 inches in height (38 mm), with the jetting array being 0.47 inchs by 2.93 inches (11.8mm x 74,5mm).

To describe the fluidic layout of the head we start with the single jet. Figure (3) shows the individual jet. In this picture all the metal has been "etched" away and only the fluid has been left. It is to note that the jet consists of a properly sized inlet that acts as an inductive valve, a body where the pressure pulse is generated, an outlet which transfers the ink from the body to the aperture, and finally the aperture from which the drop is ejected.

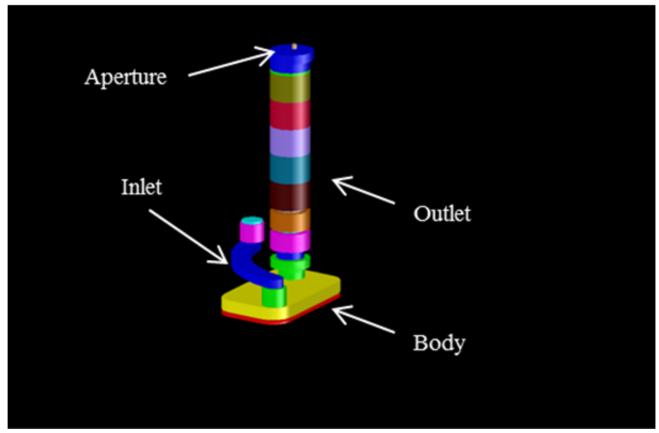

Figure 3. *M-series single jet.*

To move fluid from feed ports to the 880 individual jets, a complex manifold system is used. The manifolds consist of a main manifold that takes fluid from the inlet ports at the back of the stack and transfers it to "finger" manifolds, which in turn feed the individual jets. Figure (4) shows a detail of the fluid path for the manifold system (again the metal has been "etched" away), emphasizing the "finger" feed system.

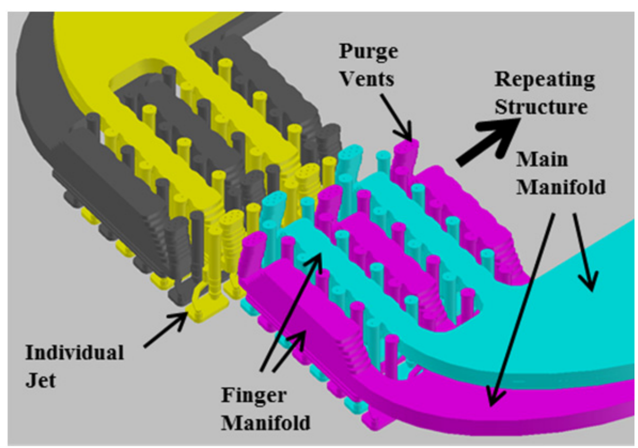

Figure 4. *Detail of fluid path for manifold system.*

It should be noted that Figure (4} shows two main manifolds overlapping one another, with one being above and one is below.

This allows for two fluids to print in the same region. Something that is not shown in the figure but is critical to manifold performance is compliance. In the Xerox M-series head, a compliant wall makes up the top surface in both the main and "finger" manifolds. This compliance acts as a fluidic dampener to reduce the effects of fluidic cross talk and fluidic inductive load. This is a feature that has been incorporated into Xerox heads for several years [2].

The fluidic layout for the Xerox M-series print head is such that it can actually jet 8 different fluids. The manifold structure is mirrored along both the horizontal and vertical center lines, which effectively breaks the head into 4 fluidic isolated regions. Figure (5) shows the fluid path and these 4 different regions. Because each region allows for two fluids, the print head is thus capable of jetting a total of 8. The ability to jet 8 independent fluids at the same time, from a high performance print head, is unique in the market today. This allows for a system integrator to use a single head in the place of many, thus reducing system cost and improving performance.

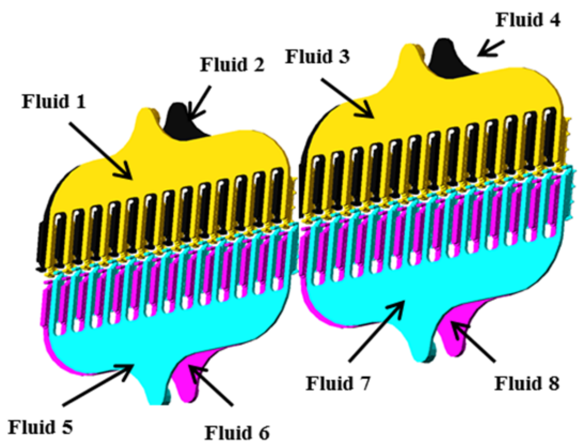

Figure 5. *Fluid path for 8 different fluids.*

Since the M-series print head was originally designed for waxed based inks, it has a film heater attached to the back of the jet stack that allows the head to be heated to any temperature from ambient to over 140 C. The heater can be powered by either AC or DC power. However AC is generally preferred, due to system level cost implementation. To control temperature the print head uses a two zone control methodology. There are two thermistors buried in the jet stack itself, one on left and one on the right. The temperature readings from these thermistors are converted to digital output, which is serially relayed from the head. Using an appropriate thermal controller, this will allow the temperature of the head to be controlled within +/- 1 C.

Head Performance

The Xerox M-Series print head is designed to run at frequencies up to 43 kHz. The drop sizes it can eject at that frequency range from 17 pl to 28 pl. This can be done easily with this print head, since it uses an infinitely adjustable analog waveform to drive the PZT's. An example of this waveform, showing how it corresponds to drop ejection, is shown in Figure (6). By varying the prefill, ejection, refill, or cancelation parts of the waveform, the characteristics of the formed drop can be modified. This ability to infinitely modify the waveform is also an incredible advantage in extracting optimal performance from the wide variety of fluids that the print head can jet.

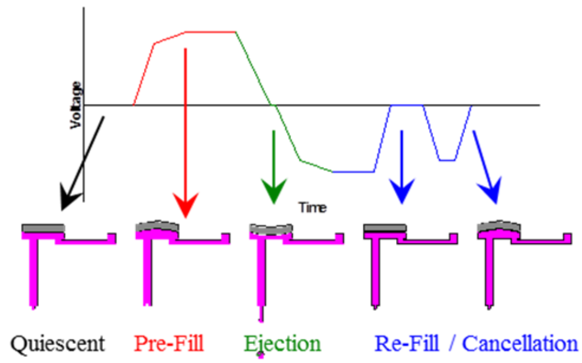

Figure 6. *Xerox M-series Waveform.*

Figure (7) shows jetting of a wax based ink and aqueous ink with the print head. The pictures show the nicely formed drops that can be ejected with the Xerox print head. This is due not only to the design of the individual jet and manufacturing process, but to the ability to adjust the wave form to tune out the parasitic resonances that are present in high frequency ink jet print head designs. It should be noticed that the jetting velocity of the aqueous ink was at 10 m/s, which is comparable to all piezoelectric print heads on the market today.

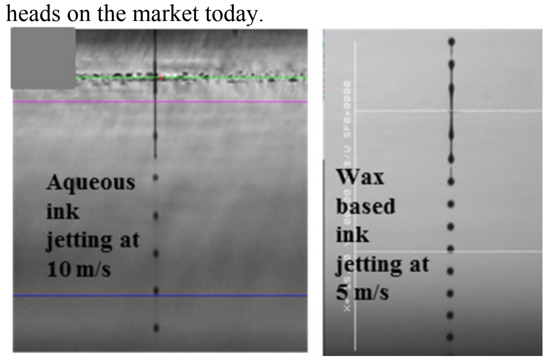

Figure 7*. Examples of M-series print head jetting aqueous and wax based fluids.*

The M-series head is currently designed to operate with fluid viscosities in the range from 6cp to 11cp. It should be emphasized that this is the "operational range". Since the head can be heated, fluids with higher viscosities at ambient temperatures can be heated up to jet in this head. Again this allows for a wide variety of fluids to be used with this head. In regards to allowable fluid density for the head, successful testing has been performed with fluids that range from .7 gm/cm^3 to 1.2 gm/cm^3. However it may be possible to jet fluids with both lower and higher densities. In regards to the requirements for a fluids surface tension, the M-series heads have been tested with fluids ranging from 22 to 40 dynes/cm. However as with density it may be possible to jet fluids with lower and higher surface tensions.

The interested reader will find a great review of the fundamentals of ink jet fluid modeling and design in an "Overview of Phase Change Piezoelectric Ink Jet Fluids Modeling and Design" by Burr, et. al. [3].

Head Calibration

The Xerox M-Series print head has the capability of being calibrated coarsely on an overall print head basis, as well as fine calibration on a jet to jet level. This fine adjustment on a jet to jet level is a unique feature offered by the Xerox print heads. This ability can be used to calibrate out manufacturing variation, as well as to compensate for the viscosity differences of two different fluids jetted through the head at the same time.

The coarse calibration is done by adjusting the drive waveform that is sent to the print head, by increasing or decreasing its amplitude. Thus the average drop volume and jet velocity can be set for the head. The fine jet to jet calibration in the Xerox M-series print head is made possible by the custom designed ASIC's that are used to drive each nozzle. These ASIC's can be programed by a print head user to disconnect the voltage at a specific time during the waveform. Since the PZT's are effectively capacitors they hold their voltage until they are reconnected during the falling edge of the waveform. This ability to calibrate on a jet to jet basis effectively allows for a very fine adjustment of the performance of each jet. The calibration range for the M-series print head has a total of 64 levels. The magnitude of these levels can be determined by how the user decides to design their waveform. Calibration values for the head can be serially loaded, as digital information, into the head any time the print head is not firing,

Reliability

The Xerox M-Series print head is an extremely reliable industrial print head. Because of its brazed stainless steel construction, it is incredibly durable to physical abuse. It has been designed for both extreme cycling of the single jet driving structure and thermal cycling of the entire head. In current reliability testing there has not been a limit found as of yet in regards to cycling the driver. So far heads have been cycled to 150 billion actuations and are still going. In regards to thermal cycling of the heads, Xerox has cycled heads to over 10,000 cycles in which the heads were taken from ambient to 140 C. Again these heads have had no failures.

Another area of concern for print head reliability is hard failures of the individual jets that are not recoverable by a purge. For the Xerox head it has been found that when a clean head feed system, with proper pre-filtration, is implemented the heads are practically immune to intrinsic failures. It has been found that intrinsically they are 99.8% reliable on a per head basis (i.e. not a single missing jet). This is of course is excluding external damage and contamination introduced by improper use or maintenance of the head. This high degree of reliability is due to the design and construction of the print head. In particular there is an internal jet stack filter that prevents hard particles greater than 33 microns from reaching the apertures.

Head Implementation Guidelines

To properly implement the M-series print head in a system there are a number of key items that should be accounted for. The user must maintain a negative pressure head at the aperture, properly mount the print head, implement a head maintenance system, and make the proper fluidic and electrically connections.

To maintain proper jetting performance, a negative pressure head at that apertures it required of 0.5in to 3 in of water. This can be maintained in multiple ways. For some applications in which the Xerox head has been used, the free surface is in an attached reservoir below the level of the apertures. Thus thru a siphon effect the negative pressure head was maintained. In other applications an active vacuum has been used to maintain the required negative pressure.

For proper performance of the head, periodic head maintenance is required. This can be due to the occasional missing jet, or bringing the print head up from a nightly shutoff. Maintenance can be performed by either pressure purging or by using a vacuum purge (i.e. anything that drives a pressure differential). To purge the print head a pressure profile can be used similar to Figure (8). The fluid volume to purge the print head is on the order of 3 ml of ink. However it must be noted that additional ink may be required dependent on how the fluid interface to the head has been implemented.

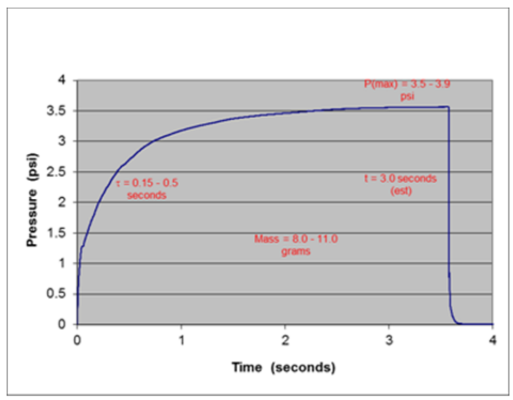

Figure 8. *Example of purge profile.*

Once the head has been purged it is critical to maintain the print head to remove fluid that has been left on the aperture plate after the purge. Both wiping and vacuum systems have been implemented with the Xerox M-series heads, and have proven effective in removing this ink. An example of a fluorosilicon wiper that Xerox uses to remove fluid following a purge is shown in Figure (9).

The Xerox M-series print head is mounted using screws and clamps. One implementation of this mounting scheme is shown in Figure (9). When mounted properly the Xerox head is flat to within 50 microns. Because of the aperture layout of the head it should be noted that it is sensitive to roll. If the roll is not correctly adjusted there will be a break in coverage (i.e. a spacing) every 16 vertical lines.

The fluidic interface to the head is thru 8 individual ink ports in the back of the print head. An important consideration when connecting to the head is that the feed system, either by an attached reservoir or fluidic interface, is sized properly to minimize fluidic inductance and resistance. At Xerox we use silicon port gaskets as shown in Figure (10) to make the fluidic seal between the print head and reservoir, or fluidic interface.

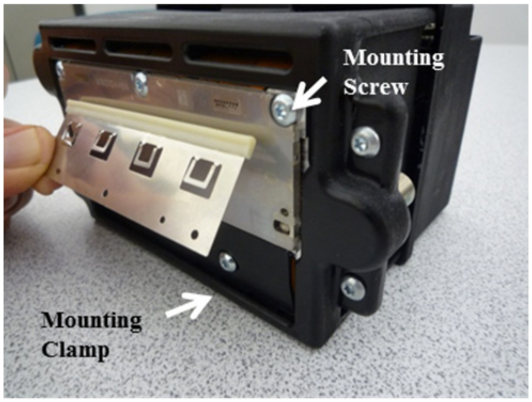

***Figure 9**. Example of Xerox Wiper Blade and head mounting.*

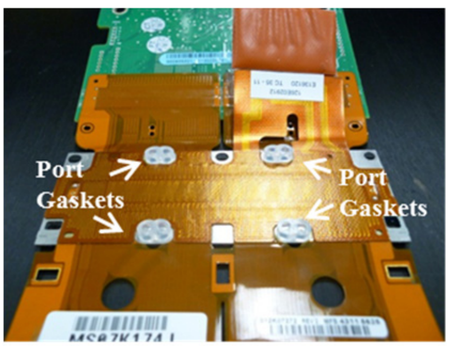

***Figure 10**. 8 ports on the back of the Xerox print head and its port gaskets.*

The electrical interface to the M-series print head consists of three connections. They are a flat custom designed flex cable to input the wave form, a flat data cable for a high speed and slow speed serial interface, and a heater cable to connect up to the film heater on the print head. During print head operation data is continuously sent thru the high speed serial interface. This data is used to enable jets for each firing cycle of the print head. This high speed interface is also used to set the calibration values for the head when it first powers up, or if the user decides to change them during operation, when the head is not firing. The slow speed interface is used to digitally communicate the temperature of the print head for thermal control. It is also used to upload and down load information to a NVRAM chip on the print head, which enables the user to store head specific data.

Current Uses of the Head

The Xerox M-series print head was initially designed and manufactured for internal use by Xerox (see Korol [1]). It currently is used in the Colorqube 9300 series of printers and in the CiPress500, both shown in Figure (11). The Colorqube is a work group office printer which uses a 4 color version of the print head and aligns them into a full width array (see Korol [1]). The CiPress500 on the other hand is an industrial scale continuous feed printer that prints at 500 ft/min. This system aligns 56 print heads (14 per color) to form a single pass array at 600 dpi. Figure (12) shows a picture of how these heads are arranged to enable true single pass printing. From these systems one can understand the versatility of the head for both small and large industrial applications.

***Figure 11**. Xerox's Colorqube 9301 and CiPress500.*

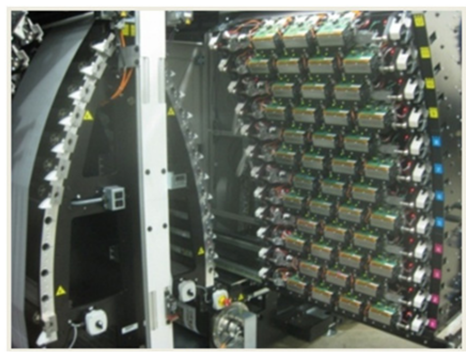

***Figure 12.** Print head array in Xerox's CiPress500.*

Because of the unique attributes of the M-series print head is beginning to find multiple applications in the industrial world outside of Xerox. One interesting use of the head is by the Schmid Group located in Freudenstadt Germany. Schmid uses the M-Series print head in a specialized process to make solar cells. The head is one of the keys that enable their selective emitter process, which is used to increases the efficiency of the solar cells. Schmid takes advantage of the ability of the head to jet high temperature fluids. It uses the head to print a wax like removable photo-mask that allows selective etching of the cells. An actual pattern printed on a solar cell is shown in Figure (13).

Another commercial application of the print head is by TecOptic located in Chambéry France. They also take advantage of the high temperature aspects of the head, jetting a wax based material to print on eyeglass lenses before they are cut to fit into frames. The heads will place marks on the lenses that show the location of the optical center, as well as label them. The wax has the advantage that it is easily removable after the lenses have been cut. Figure (14) shows the printed image on one of these eyeglass lenses.

Still another use of the Xerox technology is in 3D printing. 3D Systems use an 8 inch Xerox print head, constructed using the same methodology as the M-series print head, to make 3D parts. They do this by jetting a UV curable build material, and corresponding support material that can be easily removed once the part is made. 3D Systems takes advantage of the highly chemically inert nature of the M-series head, and its robust performance, to ensure the viability of the parts it prints. If the reader has seen three dimensional printing they know it is one of the most extremely demanding applications for a print head. It requires a high degree of operation robustness, and the jetting of massive amounts of fluid. Figure (15) shows a part printed by 3D Systems with a Xerox print head.

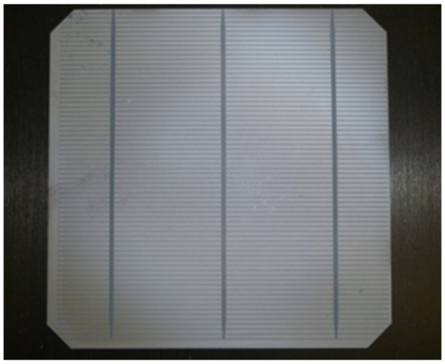

Figure 13. *Etch mask printed on solar cell with M-series print head.*

Figure 14. *Image printed on pre-cut eyeglass lens with M-series print head.*

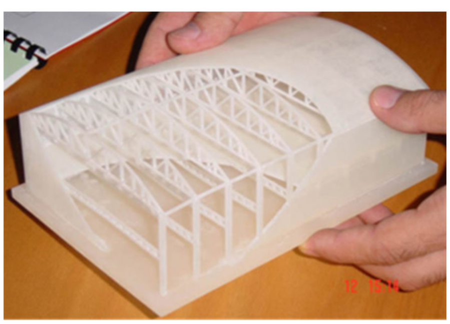

Figure 15. *3D part printed with a Xerox 8 inch print head.*

Future Versions of the M-Series Printhead

Xerox is looking to expand in the industrial print head market, and in the future wants to extend the capabilities of the M-series head. By leveraging on the supreme attributes of the head, Xerox is planning on developing a high viscosity version of the M-series that is capable of jetting fluids up to 20cp. This high viscosity performance, coupled with the heads high temperature operation, will allow this head to jet fluids that cannot be used by any other head. Xerox is also planning to develop a small drop version of the M-Series head that can jet drop volumes down to 3 pl. This will enable applications with the print head that require the smaller drop size. Of course this version of the head will still maintain its high temperature operation. A recirculating version of the M-series print head is also in the works at Xerox. This head will again retain all the advantages of the M-series head. However it will enable applications that want to jet high pigment or particle loading. This will be due to the fact that the head will be able to continuously recirculate fluid throughout the head, thus suspending heavy particles in the fluid stream.

Conclusions

Digital printing fabrication and industrial printing is, as stated at the start of this paper, an area of great technological growth. This growth would not have been possible without the advancements that have been made in the performance and design of the print head technology that is at the core of this technological explosion. The M-series print head that Xerox has developed will be a key enabler today, as well into the future, for the growth of digital fabrication and industrial printing. This industrial strength print head can jet any fluid that will not react with stainless steel, gold, or Teflon, and can do this jetting at temperatures ranging from ambient to 140 C. It operationally can jet more fluid per linear inch that almost any print head on the market today. It has the ability to jet 8 different fluids at one time, something that no other print head can do, and because of its industrial design and construction it is extremely reliable and robust. Also the electronics driving this print head are unique in the market, enabling jet to jet calibration that can be used to adjust for manufacturing variation, or viscosity differences between different fluids jetting at the same time. Xerox is expanding into the industrial print head market and the current M-series print head, as well as future variations of the head, should be a major contributor to advancing the revolution of digital fabrication and industrial printing.

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Author Biography

David Tence is the Jetting Development and OEM Print Head Project Manager for Xerox's Print Head Research and Development group. He received his Bachelor and Master's degree in Mechanical Engineering from Oregon State University. His area of emphasis was fluid mechanics, focusing on micro fluidic flow. Mr. Tence has worked on solid ink print head design and development for Tektronix and Xerox for the past 21 years. Throughout his career he has been responsible for many aspects pertaining to the productization of multiple generations of solid ink print heads. Aspects such as core research, fluidic layout and design, robust operation, manufacturing calibration, system integration, project management, group management, and technology direction.