White Paper on Critical National Need Idea

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[1] Merging between OMAX Corporation and FLOW International Corporation is expected to complete by March 2009

Advancement of Versatile Waterjet Technology to Rebuild Competitiveness in Manufacturing Technology

Executive Summary

In the current economic crisis, several hundred thousand manufacturing jobs have been and many more are expected to be cut. This white paper attempts to help recover the manufacturing sector by creating new jobs while curbing outsourcing through rebuilding America's manufacturing leadership and competitiveness. We propose to meet the above societal challenge through advancing and promoting one of the emerging and yet most promising manufacturing processes: ultrahigh-pressure waterjet technology. Since commercialized in 1970s, waterjet technology has gone through significant transformations, leapfrogging from merely a niche cutting tool to a precision machine tool competing on an equal footing with established machine tools. The versatile waterjet technology possesses several inherent merits that could not possibly be achieved by most of these established tools. As more and more waterjet systems are inserted into the manufacturing arena, manufacturers have discovered that waterjet machining fits well with the "just in time" practice of lean manufacturing. Using waterjet machining, most parts, small and large, could be completed from design to finish in two to three days or sooner. This could not possibly be achieved by outsourcing the same parts abroad. Testimonials from small and large customers have repeatedly indicated that installing waterjet machinery in their shops is one of the best moves to save their jobs from shipping abroad. According to Frost and Sullivan, waterjet machine tool had emerged as the fastest growing segment of the overall machine tool industry in the last decade and this same trend is expected to continue in the next decade.[2] Surveys have shown that even faster growth could be achieved if the awareness of the technology were raised. Most importantly, the emerging technology still has considerable room for innovation with potential to expand its role into precision machining for advanced manufacturing. This white paper proposes a dual approach to develop the next-generation waterjet technology and to raise the awareness of the technology: (1) conduct high-risk, high-reward R&D and (2) promote waterjet technology by offering design and manufacturing course work in institutions of higher education (universities and technical/community colleges) and establish waterjet demonstration centers accessable to hobbyists and individual art and craft professionals. We have signed on collaborators from academic/nonprofit institutions, national laboratories, and manufacturers. Developing novel waterjet processes would broaden applications of waterjet machining toward high-value-added jobs, and raising the awareness of the tehcnology would encourage the ownership for waterjet machine tools by small and large businesses alike, which could then lead to creation of new manufacturing jobs. Only the reversing of the three-decade-long trend of continued shrinkage of domestic manufacturing workforce will lead to a lasting solution to revitalize the once prosperous manufacturing business and contribute to a recovery of America's economy from its current crisis.

1. Introduction

In recent years, thousands of manufacturing jobs have been lost. This job loss has been accelerated in 2008 as the economy worsens. Stimulating packages passed by Congress and being contemplated by the Administrations are designed to help boost the ailing national economy. A portion of these packages are aimed at rebuilding our manufacturing industry. One of the most societal challenges in rebuilding our manufacturing industry is through regaining competitiveness and emphasizing on innovation and productivity. As such new jobs to be created as our economy turns around would stay domestically rather than shipping abroad.

The importance of manufacturing to our nation's economic leadership and prosperity cannot be overstated. Our economic growth is powered by manufacturing. By itself, U.S. manufacturing output is greater in size than the eighth largest economy in the world. Our manufacturers pioneer the innovations, technology and methods that maintain this nation's economic leadership. And it's important that we remain as the economic leader in the world, for the good of our people. Our nation's standard of living depends on our manufacturers. America's manufacturers provide our people with rewarding careers and high-paying jobs. Manufacturing jobs pay over 20 percent more than the national average. For decades our manufacturers have faced the pressures of increased competition and globalization. Many developed and developing countries have caught up with the U.S. in manufacturing technology. Compounded by the difference in labor costs, many manufacturing jobs have been lost to outsourcing. Drastic measures are needed in order to reverse the trend of shrinkage of America's manufacturing workforce. In order to promote manufacturing technology and maintain our global lead, an executive order 13329 on "Encouraging Inno-

[2] Frost and Sullivan – "The World Waterjet Cutting Tools Markets" Date Published: 30 Aug 2005 (www.frost.com)

vation in Manufacturing" was established in 2004. Stimulus packages just passed and under consideration by our government are also in part aiming at rebuilding America's manufacturing industry.

Meeting the above societal challenge by rebuilding America's leadership and competitiveness in manufacturing technology would require inventing/reinventing novel manufacturing processes that are cost effective with high productivity, versatile, user and environmentally friendly, and compatible with lean manufacturing practices (e.g., fast turnaround for just-in-time manufacturing). The emerging waterjet technology appears to have the ingredients that qualify to be one of such processes. Since commercialized in 1970s, waterjet technology has gone through phenomenal transformations, leapfrogging from merely a niche cutting tool to a mainstream precision machine tool competing on an equal footing with lasers, EDM, ultrasound, photo chemical etching, and most CNC machine tools. Waterjet technology possesses several inherent merits that cannot be matched with most other machine tools and yet there is considerable room for technological improvement to expand its role as a versatile and precision machine tool. In essence, the low capital costs and user friendliness of waterjet machine tools are attractive to small and large businesses to own and operate with a good profit margin. The cost effectiveness and fast turnaround of waterjet machining enable job completion from beginning to end typically in two to three days that cannot be possibly achieved by outsourcing the same parts. Manufacturers have begun to realize that waterjet machining is especially ideal for just-in-time manufacturing – an important component for lean manufacturing practices. Testimonials from small business customers who conduct subcontracting work have repeatedly indicated that the very cost effectiveness and fast turnaround of waterjet machining have helped them save their jobs that normally would have been outsourced abroad.[3] In fact, NIST has installed an OMAX JetMachining® Center Model 5555 in its full-service fabrication shop. NIST's staff and technician have the first-hand experience in the merits of waterjet technology (http://www.omax.com/spotlight.php).

Waterjet machine tools have experienced steady increase in adoption by the manufacturing industry. As a result, they had emerged as the fastest growing segment of the general machine tool industry in the last decade, according to Frost and Sullivan.[1] The same trend is expected to continue into the next decade. The lack of awareness of this technology is reported to be one of the main impediments preventing even faster growth. Moreover, the relatively young waterjet technology has considerable room to grow technologically, leading to further expansion in its role as a machine tool, particularly in the fields of rapid prototyping, machining delicate and extremely hard materials, and micromachining. Such high-reward applications would require development of the next-generation waterjet technology through high-risk R&D. Currently, the market share of waterjet machining is less than $1B whereas the total market share of machine tools is $50B. As the role of waterjet machining expands, its market share is expected to increase proportionally.

The promotion and advancement of waterjet technology could be accomplished in three areas described briefly below and elaborated in Section 4: (1) conduct high-risk and high-reward R&D to expand the role of waterjet technology, particularly in precision and delicate machining with high profit margin for our customers; (2) increase the awareness of waterjet technology through education, delivery of presentations in technical conferences and trade shows; and (3) set up demonstration centers for potential users. We will invite academic research institutes, national laboratories, and private industry to collaborate in this endeavor.[4]

In this white paper, we address in Section 2 the societal and technical challenges for restoring America's leadership and competitiveness in manufacturing technology, respectively. Section 3 briefly describes the waterjet technology, particularly its inherent merits that have the potential to meet both the societal and technological challenges with the goal of creating new manufacturing jobs that stay rather than being outsourced abroad. Section 4 describes the three approaches proposed for the promotion and advancement of waterjet technology together with collaboration from various organizations. Section 5 addresses the need for federal funding. A summary is given in Section 6.

2. Waterjet Technology

Waterjet technology was commercialized by the Washington-based Flow Industries in the late 1970s. The PI and many of his colleagues were actively involved in the commercialization of the technology and have witnessed and contributed to its rapid maturing. Through intensive R&D supported by external (e.g., SBIR/STTR, NCMS, and

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[3] http://www.modernmetals.com/common/ArticleSearchDetail.asp?CurrentPage=7020

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[4] OMAX has worked with organizations such as, NIST, MIT, University of Washington, Oregon State University, Pacific Northwest Laboratories, Boeing, GE Aviation, Rolls Royce, Pratt & Whitney, Carnegie Institution of Washington, and others.

Kodak) and internal funding, waterjet technology has leapfrogged from merely a niche cutting tool to a mainstream precision tool, competing on an equal footing with other well established machine tools.

2.1 Waterjet Machine Tool

2.1.1 Basic hardware and software

The principle of ultrahigh-pressure (UHP) waterjets is quite simple and straightforward. Refer to the website www.omax.com for a detailed description of the technology and its applications as a precision machine tool. In brief, UHP water delivered from a high-pressure pump up to 600 MPa is forced through a tiny orifices with diameters ranging typically from 0.2 to 2.0 mm to form a skinny high-speed waterjet (WJ) that has the erosion power to cut through relatively soft materials. The above configuration is the water-only-nozzle (WON). For metal and other hard materials, an abrasive-waterjet (AWJ) by entraining abrasives such as garnet and aluminum oxide via the jet pump effect (vacuum generated when the jet is form downstream of the orifice) are used into the waterjet. The abrasives are accelerated inside a carbide mixing tube attached to the end of the WON. Operating at 340 MPa and using garnet as the abrasives, AWJs are capable of cutting most materials. For precision machining, the WJ/AWJ nozzles are mounted on a 2D/3D traverse with resolution as fine as ±25 micron. CAD/CAM software packages are developed to design the toolpaths for cutting parts and move the nozzle following the designed toolpaths during cutting, respectively. The cutting tolerance could be as small as ±25 micron. Depending on the combination of the diameters of the orifice and mixing tube, features as fine as 250 micron are routinely cut by AWJs. As a rule of thumb, micromachining is defined as machined features smaller than 150 micron. The PI has recently developed a novel AWJ process, SAWS, for machining features below 100 micron.[5]

2.1.2 Novel processes

Another format of waterjet machine tool is the abrasive slurry jet (ASJ). Instead of entraining abrasive via the jet pump effect, abrasive slurry is directly pumped through the orifice such that the average speed of abrasives is considerably higher than that of the AWJ. As a result, the erosion power of ASJs is up to five times that of AWJs. At present, ASJs operating at up to 200 MPa are commercially available. The lack of engineering materials that could resist the high-wear characteristics of ASJs prevents ASJs operating at pressure higher than 200 MPa. In general, the beam diameter of the two-phase ASJ is considerably finer than the three-phase AWJ. The feasibility of using ASJ for micromachining has been established (Miller, 2005, 2006). Development of ASJs operating at pressures above 200 MPa to take advantage of the high erosion power will be one of the proposed R&D tasks.

OMAX is a premium manufacturer of waterjet equipment for precision machining. A product line of JetMachining® Centers with various footprints and precision were available commercially (http://www.omax.com/machines.php) for a wide range of machining applications. Since established in 1993, OMAX has rapidly grown into a $60M company that had nearly 40% annual growth for five out of the last six years. OMAX was among the Inc. 5000 fastest growing private companies in America in 2008 (http://www.inc.com/inc5000/2008/the-full-list.html) and was the recipient of the 2005 Frost & Sullivan Award for Product Value Differentiation in the waterjet cutting tools space because of its significant market share in the waterjet machine tools market.[6]

Supported by internal and external funding including SBIR/STTR, OMAX has actively engaged in R&D toward advancing waterjet technology. We have leveraged collaborations among OMAX and academic institutes (e.g., University of Washington, Oregon State University, and Washington State University), national laboratories (e.g., PNNL and NIST), and industrial firms (e.g., Boeing, GE Aviation, Rolls Royce, and Pratt & Whitney) to maximize R&D resources. We will continue doing so for the proposed endeavor. Under the sponsorship of DoE, DoD, and NSF SBIR/STTR, OMAX has demonstrated the feasibility of applying AWJs for machining high-aspect-ratio slots/ribs that cannot be otherwise achieved with other machine tools (Liu et al., 2008). These high-aspect-ratio slots/ribs are one of the key components for forming flow channels used in fuel cells, heat exchangers, reformers, and reactors. Active R&D in microfluidics is being conducted to downsize these devices for improved efficiency and portability (http://oregonstate.edu/conferences/MNBC/090808/paul.pdf). The demand for waterjet machining of composites for aerospace applications has steadily increased in the last three decades (Hashish, 2008). In the near future, as the R&D in micro-nano technology begins to bear fruits, the need of low-cost tools for manufacturing arrayed microchannels is expected to increase dramatically when micro-nano devices are commercialized. Timely

[5] An invention disclosure on the SAWS has been prepared

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[6] www.frost.com, World Waterjet Cutting Tools Market

development of the next-generation waterjet technology is a must in order to meet the future demand for delicate machining and micromachining.

Although AWJ is so powerful that it could cut virtually any materials, it could induce damage in delicate materials (e.g., laminates, composites, and extremely brittle materials) if its raw power is not controlled properly. The damage is caused by the buildup of static pressure inside the blind hole during the initial stage of piercing before breakthrough. The kinetic energy of water droplets in the WJ/AWJ converts back to potential energy (i.e., the static pressure) as the jet decelerates, stops, and reverses its direction inside the blind hole (Liu and Schubert, 2008). Any materials with an ultimate or tensile strength below the static pressure would be subject to piercing damage. Under the sponsorship of an NSF SBIR Phase II grant, OMAX is developing a flash abrasive-waterjet (FAWJ) by superheating the high-pressure upstream of the orifice (patent pending - Liu, 2007). The superheated water evaporates upon exiting the orifice. Most liquid water escapes before the AWJ penetrates into the workpiece. Therefore the static pressure buildup induced by the FAWJ inside the blind hole reduces drastically. Piercing damage to most delicate materials is mitigated. Therefore, the FAWJ has helped realize the full potential of waterjet technology as a truly material independent machine tool and is another important characteristic for universal machining.

2.2 Merits of Waterjet Machining

Waterjets have the following inherent merits that cannot be matched with most other machine tools:

- A cold process that does not generate heat-affected zones (HAZ) to compromise the structural integrity of machined parts (Liu et al., 2008)
- A material independent process – that is environment and user friendly (Liu and Schubert, 2008)
- User friendly and highly automated PC-based CAD/CAM software for low-cost precision manufacturing
- No tooling that is cost effective with a fast turnaround for large and small lots (for production and R&D) and no tool to break when machining extremely hard and tough materials
- Multi-machining mode allowing roughing, parting, drilling, turning, milling, and grooving, etc. in a single setup with no need for tool change and part transfer
- Amenable to stack and 3D machining
- Machining of high-aspect-ratio ribs/slots (through or blind) that cannot be matched with any other machine tools (Liu et al., 2008)
- Feasibility for micromachining demonstrated (invention disclosure)
- Ideal as a primary tool for net shaping when exceptional precision is needed (enhancing productivity and extending life of expensive coated tools used in the secondary trimming/polishing process
- Machining composites/titanium at speeds higher than those achievable with most mechanical tools.

3. Meeting Societal and Technological Challenges

As stated in Introduction, our national is in the midst of an economic crisis that must be resolved immediately before the situation deteriorates even further. In the past year, hundreds of thousands of jobs have been lost in the manufacturing industry alone; additional jobs are expected to be lost before the economy turns around. Our government has passed rescue/stimulus packages, with additional follow-on measures, to cope with the crisis for speedy recovery. The key to recovery is knowing how to optimize the usage of these packages to maximize the results. This white paper addresses the issue of rebuilding the lost leadership and competitiveness of America's manufacturing technology through advancement and promotion of waterjet technology, a U. S. invention that was commercialized in the late 1970s. This relatively new technology has all the ingredients to be the next-generation machine tool with the potential to help revitalize America's manufacturing industry. In this section, the relevant societal challenge on domestic job creation in manufacturing to be met by the proposed R&D will be described and discussed. Technological challenges will be discussed that must be overcome during the course of proposed R&D in order to maximize the impact will be discussed.

3.1 Societal challenge

As stated in previous sections, many manufacturing jobs have been lost to outsourcing in the past three decades. Compounded by the current economic crisis, many more domestic manufacturing jobs have been lost. Unfortunately the established trend has clearly shown that job loss to outsourcing is expected to continue even after the economy is revived. Drastic measures must be taken to buck the trend so that new jobs created as the economy recovers would stay in America rather than mostly being outsourced. Therefore, one of societal challenges is determining how to rebuild the lost leadership and competitiveness of America's manufacturing industry. Base on recent marketing data and the social impact of waterjet technology, the proposed R&D is designed to meet the above challenge. Once the leadership and competitiveness of the manufacturing industry are rebuilt, we anticipate that the threat of outsourcing jobs abroad would be eliminated.

- Keeping manufacturing jobs of all skills in the U. S. – the cost effectiveness and fast turnaround of waterjet machining have saved many manufacturing jobs from being farmed abroad. Many OMAX customers have benefited from their jobs being saved in the U. S. As a result, the waterjet machine tool market was rated as the fastest growing segment of the general machine tool industry in the last decade, and the trend is likely to continue in the next decade, according to Frost and Sullivan (www.frost.com). The promotion of waterjet technology and expanding its role in precision machining through technological breakthrough would result in saving more jobs, particularly high-paid ones, from being lost to outsourcing.
- Promotion of small businesses in manufacturing - U. S. small businesses represent a large percentage of the nation's economy. OMAX has sold over 40% of its JetMachining Centers to companies with 10 or fewer employees, particularly job shops. An increase in OMAX's sales would directly translate into an increase in production through small businesses and/or the establishment of new small businesses.
- As pointed out in early sections, the lack of awareness of the merits of waterjet technology has been one of the key impediments that prevent it from growing at the maximum rate. We will have to rely on education and technical presentations to raise the awareness of the technology. The academic program at MIT presents a perfect example of raising awareness through education. MIT has installed six OMAX JetMachining® Centers (JMCs) for its students to use.[7] In the Mechanical Engineering Department, a design course is offered exclusively for using the JMC as the only machine tool. We will consider expanding such education scenarios to other academic institutes as a means to promote industrial use of waterjet machine tools.
- There is considerable room for waterjet technology to grow in several areas of advanced manufacturing: mobile machining for field services, precision machining of virtually any materials for industrial applications, machining aerospace composites and metal alloys, 3D machining, micromachining, and others.[8] In fact, mobile machining would lead to a paradigm shift in the current machining technology. High-risk and high-reward R&D however would be required to develop the next-generation waterjet technology in order to rebuild the competitiveness of U. S. manufacturing in terms of technological superiority, cost effectiveness, and productivity. For example, novel processes must be developed to unleash the potential of waterjet micromachining and 3D and mobile machining.

3.2 Technological challenges

In the past three decades, many new materials such as alloys and composites have been developed for various industrial, medical, energy, and aerospace applications. Micromachining has become one of the most active R&D activities in manufacturing technology as MEMS technology matures and becomes commercialize. Nano technology not only further downsizes devices but also introduces integrated materials that present challenges to conventional machine tools. These new materials are often very difficult or even impossible to machine with conventional machine tools. In many cases, the manufacturing cost of devices made from these new materials are simply too high. Low-cost manufacturing will be the key to the success of commercializing these new devices.

Waterjets have been established as a low-cost manufacturing tool for many applications. The technological challenges are to develop advanced processes suitable for low-cost manufacturing components made from advanced materials using novel processes. Waterjet machining is a very complicated process by itself and is by no means fully understood. Abrasive-waterjets are a three-phase flow phenomenon (water, air, and solid) (Liu, 2007). The erosion process involves water-water, water-air, water-solid, and air-solid interaction in rapidly changing geometric environments. As such, there is considerable room for improvement through process and hardware R&D. Relevant areas that could lead to breakthrough advancements that meet the technological challenges are outlined below.

3.2.1 Mobile machining

At present, aerospace manufacturing relies on briefing large workpieces such as the fuselage of an aircraft or the whole aircraft (for repair work) to oversize facilities equipped with machine tools mounted on huge gantries. For waterjets as precision machine tools, all work for 2D and 3D machining is performed at stationary workstations. We will consider a development of a mobile waterjet machining system that would lead to shift in the paradigm shift of

[7] OMAX offers a significant discount to colleges for acquiring JMCs for educational usage.

[8] The current market capture is less than $1B out of a total of $50B for the global machine tool industry.

modern manufacturing practices. By integrating a mobile waterjet system and a local positioning system (LPS), we will be able to facilitate mobile machining in factories and in the field. The mobile waterjet system will be a PentaJet/HexaJet by mounting an abrasive-waterjet (AWJ) nozzle on mobile pentapod/Hexapod based on the principle of parallel kinematic machines (PKM) (Chen and Hsu, 2006). With five degree of freedom, the pentapod has one less linkage but is stiffer than the hexapod. The LPS with reference to the large workpiece will be used to track the position of the AWJ tip for precision machining. The LPS-based PentaJet/HexaJet will be mounted on wheels for field deployment.

A rotating platform will be added to the PentaJet/Hexajet to facilitate 3D machining. With the workpiece mounted on the rotating platform, the multimode machining capability of waterjet technology could be taken full advantage of for machining complex 3D parts via milling, turning, grooving, facing, and drilling in a single setup without tool change and part transfer.

Downsized hardware components such as the high-pressure pumps will be developed to facilitate mobile machining and to reduce capital costs. The downsized pumps will also be most suitable for manufacturing a new product line of low-cost JetMachining Centers. This would further expand waterjet machining into the consumer market serving hobbyists and individual art and craft professionals.

3.2.2 Micromachining

As stated in previous section, there is considerable demand for low-cost micromachining for fabricating energy production components, manufacturing MEMS devices, and for post processing of micro-nano products. Waterjets have the inherent merits as a micromachining tool. Current AWJ-based waterjet machine tool is capable of machining features > 250 μm due to limitation in downsizing the nozzle to create micro-size AWJs. Although the two-phase ASJs have the potential for developing micro-nozzle that could match the performance of lasers (Miller, 2005, 2006), the lack of affordable high wear resistant materials limits the operating pressures to 200 MPa (30 ksi) (Miller 2005; Liu, 2009). The cutting speeds for such ASJs would be faster than 400-MPa AWJs but is still relatively slow, particularly for very hard materials such as the SiC CMCs. With the novel process of chemical vapor deposition (CVD) that could be tuned to achieve super toughness, there is a potential to take advantage of super tough CVD for fabricating high-wear components of ASJs (Yan et al., 2002, 2004).

An alternate novel process, SAWS, has been recently developed by the PI for micromachining.[9] The proprietary SAWS does not require a special AWJ nozzle but is able to machine features 100 μm and finer. Besides, the edge quality of AWJ/SAWS-machined features is better than that of the AWJ-machined counterparts. The SAWS will be developed in parallel with the ASJ.

3.2.3 Material Independent machining

Although AWJ is capable of cutting most materials, its raw erosion power is so high that delicate materials with low ultimate or tensile strength would be damaged during the initial stage of AWJ piercing. The buildup of static or piercing pressure inside the blind hole as the high-speed water decelerates, stops, and reverses its course near the bottom of the hole is responsible for the induced damage (Liu and Schubert, 2007).[10] Any material with an ultimate strength below the piercing pressure will be subject to damage in the form of delamination, cracking, and chipping. Under an NSF SBIR Phase II grant, OMAX is developing a flash abrasive-waterjet (FAWJ) by superheating the high-pressure water just upstream of the AWJ nozzle (patent pending, Liu, 2007). Most of the superheated water evaporates upon exiting the nozzle. Only a small amount of liquid water enters into the blind hole and the buildup of piercing pressure in minimized. Preliminary test results have demonstrated that most delicate materials such as composites, laminates, and extremely brittle materials survive FAWJ piercing. With the success of the FAWJ, we have finally realized the full potential of material independent waterjet machining. In other words, the structural integrity of FAWJ-machined parts is unaltered thermally and mechanically. Preservation of the structural integrity of machined parts is one of most important merits for certain applications. We intend to optimize the FAWJ and manufacture an FAWJ kit to be added on existing and future models of JMCs.

4. Outline of Proposed Work

The proposed work will be divided into three main areas described in the next three subsections.

[9] An invention disclosure for the SAWS has been recently initiated.
[10] At 350 MPa, the compressibility is only roughly 15%.

4.1 High-risk and high-reward R&D

High-risk and high-reward R&D described in Section 3.2 will be conducted to develop the next-generation waterjet machine tools to achieve material independent machining that preserves the structural integrity of waterjet-machined parts. To take advantage of the cost effectiveness, fast turnaround, and user friendliness of waterjet machining, novel waterjet processes will be developed to facilitate machining of advanced materials and delicate parts micromachining. These are often high-valued-added jobs that would greatly benefit our customers. Novel hardware components and processes will be available for adding onto existing and future models of JMCs for broadening their machining capability.

4.2 Increase in awareness of waterjet machining

Although the waterjet machine tool segment had enjoyed the fastest annual growth rate in the last decade, the lack of technological awareness is reported to be one of the main impediments preventing it from growing even faster. We consider that raising the awareness of the merits of the waterjet technology would be necessary to accelerate its nationwide adoption. For education, we will adopt the example at MIT where six OMAX JMCs were installed. Students have the opportunity to use waterjet machine tools for carrying out design/machining course work and for fabricating parts used on various projects.[11,12] Other universities and technical/community colleges have adopted similar but relatively low-key programs. For example, Vashon College, a community college on Vashon Island, Washington, offers a course in waterjet machining and makes the technology accessible to artists and artisans.[13] OMAX encourages others to step up the effort by offering a substantial discount on its equipment to colleges for educational usage. This will be a very effective means to raise the awareness on waterjet technology. Students graduated fresh from colleges would have the know-how to take advantage of waterjet technology and apply it immediately in production environments.

Another means to raise the awareness of waterjet technology would be to establish waterjet machining demonstration centers that serve potential users. These demonstration centers are to be operated and supervised by professionals and will be opened to the public for carrying out their personal machining jobs and projects.

5. Need for Federal Funding

The current economic emergency must be put to an end quickly in order to prevent the nation from plunging into a full fledge recession. Timing is everything in rebuilding our manufacturing industry and putting our people back to work. Without federal funding, OMAX will continue conducting R&D at a pace that the company can afford. This means that it will take about five or more years to accomplish all the proposed R&D, particularly for the high-risk and high-reward R&D. By the time the next-generation waterjet technology is ready to commercialize, it would have very little impact on contribution to the recovery of the current economic crisis. On the other hand, with the federal funding, we will be able to accelerate the R&D efforts and shorten the developmental time from five or more years to two to three years. In addition, we will be able to invite all the collaborators from research institutions and industry sectors to work closely and collectively for achieving the common goal, further accelerating the progress. With the help of the federal funding and contribution from collaborators, we have the needed resources to ensure creation of new manufacturing jobs as soon as possible, hopefully within one year after the funded R&D begins. In the next several years, we anticipate a long-term trend to be established by creating more and more domestic manufacturing jobs with no incentive to be shipped elsewhere as our nation regains its leadership and competitiveness in manufacturing technology.

6. Summary

This white paper addresses meeting the societal challenge by rebuilding America's leadership and competitiveness of machining technology through advancing and promoting waterjet technology. The main goal is to reverse the trend of the last three decades of America's manufacturing workforce steadily shrinking. The proposed work would help create new manufacturing jobs that stay at home. In the midst of current national and global economic crisis, it is an urgent matter that the above societal challenge be met as soon as possible so that America will not plunge into a full fledge recession.

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[11] http://mit.nelc.edu.eg/OcwWeb/Special-Programs/SP-777Spring-2005/CourseHome/index.htm

[12] http://web.mit.edu/16.810/www/16.810_L5_Manufacturing.pdf

[13] http://vashoncbc.com/

Since commercialized in late 1970's, waterjet machining has leapfrogged from merely a niche cutting tool to a mainstream precision tool competing on an equal footing with other machine tools. There are inherent merits of waterjet machining such as material independence, multimode machining capability, and preservation of structural integrity of machined part, etc., that cannot be matched by most machine tools. The cost effectiveness and fast turnaround and low capital costs have attracted users from small and large businesses alike. Manufacturers have discovered that waterjet machining can complete most parts from design to finish in two to three days or sooner. Such fast turnaround is perfect for the "just-in-time" practice as a key element of lean manufacturing cannot be possibly accomplished by outsourcing the same parts abroad. Testimonials from our customers (particularly small business owners) have repeatedly indicated that adding waterjet machining capability into their shops has saved their job from being outsourced. As a result, waterjet machine tools has emerged as the fastest growing segment of the general machine tool industry in the last decade and the same trend is expected in the next decade, according to Frost and Sullivan.[2] Yet, there is considerable room for this emerging technology to grow as the market share of waterjet machine tools is less than $1B out of the $50B machine tool industry. Survey by Frost and Sullivan has also indicated that the lack of awareness of this technology is one of the key impediments preventing it from growing even faster.

The proposed work will focus on high-risk and high-reward R&D to develop next-generation waterjet technology for advanced manufacturing such as the paradigm shifting mobile machining, material independent precision 2D/3D machining, and micromachining. On the other hand, downsized hardware developed for mobile machining would also be available for developing a new product line of low-cost JetMachining® Centers for expanding into the large consumer machining market. In parallel to advancing waterjet technology, we will raise the awareness of waterjet technology as a versatile machine tool via increasing involvement from universities and technical colleges and delivery of technical presentations. In addition, waterjet demonstration centers will be established that are accessible to hobbyists and individual art and craft professionals.

With federal funding, we will be able to optimize our resources and focus our efforts to maximize the anticipated impact on the creation of new manufacturing jobs. Working with collaborators from various disciplines, we will prioritize the proposed tasks such that the effect of promoting of advanced waterjet technology could be realized within a year after work starts. One of the measures of success would be an acceleration in the reversing of the long-established trend of a shrinking manufacturing workforce. This would be due to the creation of new domestic jobs that would remain in this country. This anticipated accomplishment will result from the proposed tasks of a dual approach that includes high-risk R&D, higher education involvement, and community promotion. These will have a long lasting impact in rebuilding our leadership and competitiveness in manufacturing technology rather than being just a quick fix for the recovery our ailing economy.

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