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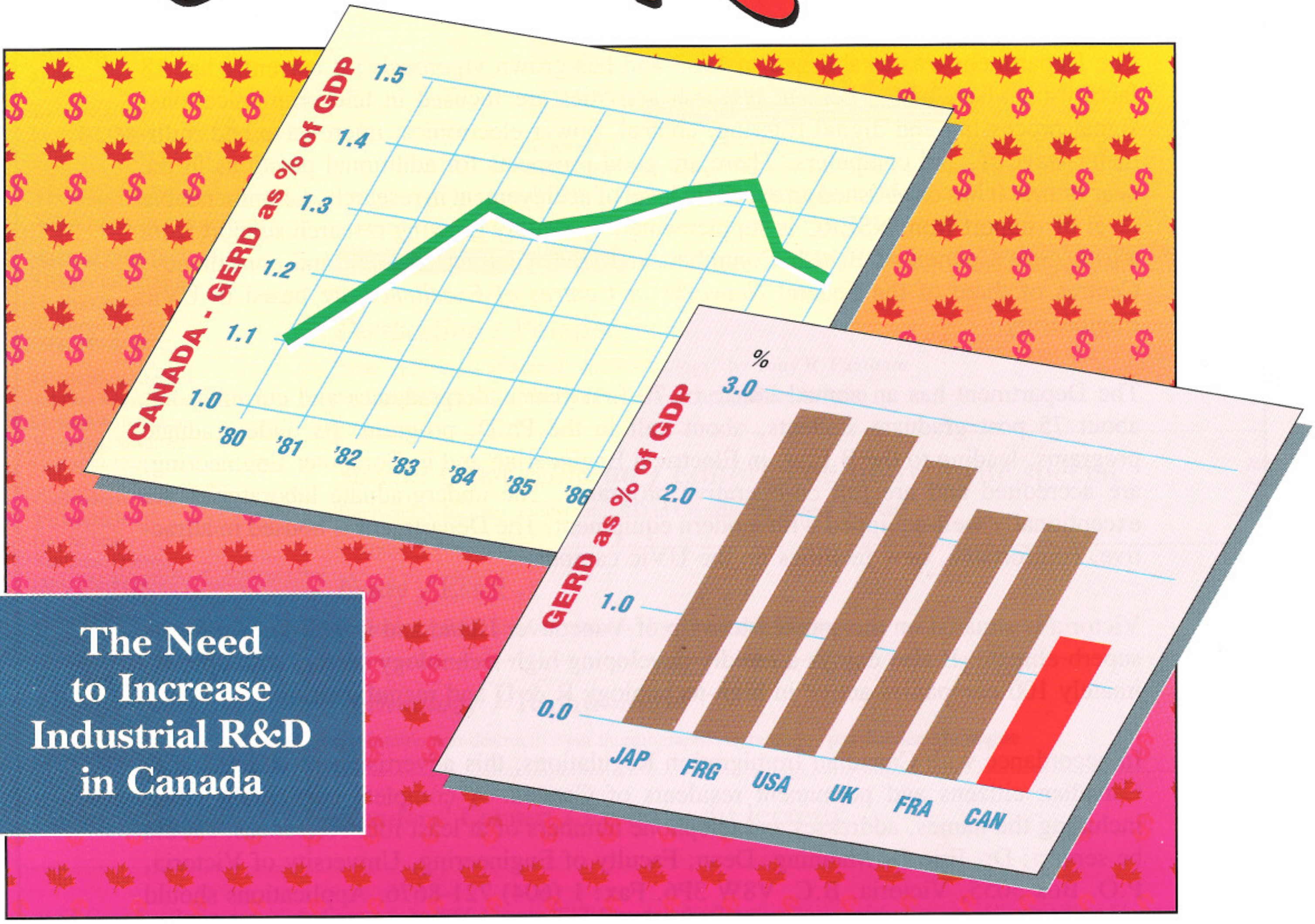

The Need to Increase Industrial R&D in Canada

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The Institute of Electrical and Electronics Engineers Inc.

Department Chair

Department of Electrical and Computer Engineering
University of Victoria

Nominations and applications are invited for the positions of Professor and Department Chair for the Department of Electrical and Computer Engineering, University of Victoria. Candidates must have an earned doctorate in Electrical or Computer Engineering or in a closely related discipline.

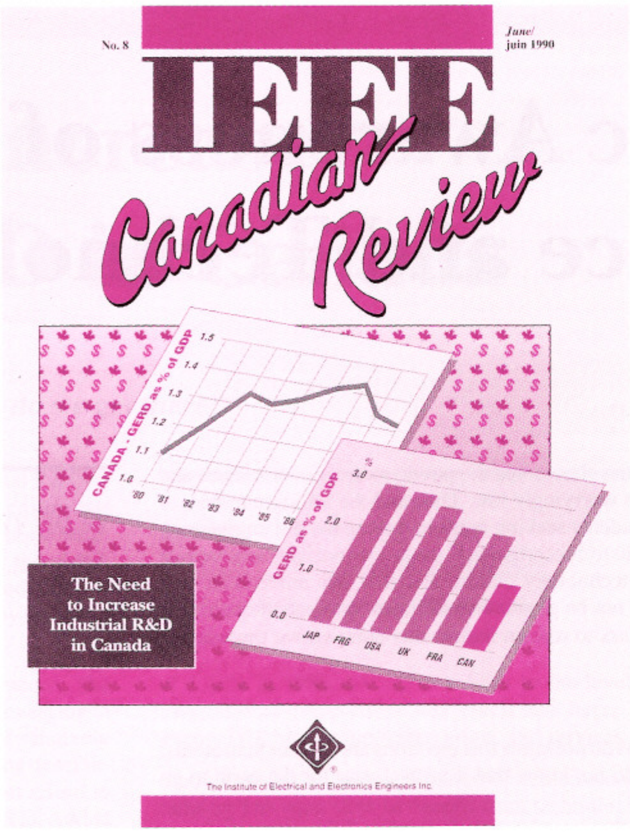
The Department Chair will provide leadership in instruction, research and service in the Department. National and international reputation based upon scholarly and professional achievement, managerial ability, and eligibility for professional registration in Canada are essential.

The Department was established in 1983 and has grown vigorously; it currently has 18 faculty members whose present research activities are focused in telecommunications, signal processing and digital filtering, control, power electronics, microwave and millimeter-wave rf, and computers. There are good prospects for additional positions in the near future. It has established an excellent level of achievement in research; a commendable level of support from NSERC is supplemented by rapidly growing research support from the Science Council of British Columbia, and from contract research and consultancy. Centres of three of the Federal *Networks of Centres of Excellence* are based in UVic Engineering.

The Department has an annual intake of 70 first-year undergraduates and currently has about 75 post graduate students, about half in the Ph.D. program. Its undergraduate programs, leading to the B.Eng. in Electrical Engineering and in Computer Engineering, are accredited and are full co-operative programs. The undergraduate laboratories are exceptionally well-equipped with modern equipment. The Department is housed in attractive, comfortable, new facilities on the UVic campus.

Victoria is situated on the southeastern tip of Vancouver Island and is well-known for its superb climate. It also enjoys a rapidly-developing high technology sector, with approximately 100 companies active in high-technology R & D and manufacturing.

In accordance with Canadian Immigration Regulations, this advertisement is directed to Canadian citizens and permanent residents of Canada. A complete curriculum vitae, including the names, addresses and telephone numbers of at least four references, should be sent to: Dr. Eric G. Manning, Dean, Faculty of Engineering, University of Victoria, P.O. Box 3055, Victoria, B.C. V8W 3P6. Fax: 1 (604) 721-8676. Applications should be forwarded before 1 November 1990.



As we enter the 1990s, technology is rapidly transforming the strategic topography of world affairs. This month, we examine some of the issues involved and how they impact on the future of the nation.

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IEEE Canadian Review is published quarterly by IEEE Canada. IEEE Canada is the Canadian Region of the Institute of Electrical and Electronics Engineers, Inc. **Address:** 7061 Yonge St. Thornhill Ont. L3T 2A6 Canada. Responsibility for the contents rests upon the authors and not upon the IEEE, or its members. **Telephone:** (416) 881-1930. **Annual Subscription Price:** Free of charge to all IEEE members in Canada. For IEEE members outside Canada: $16 per year. Price for non-members: $24 per year. **Advertising:** For information regarding rates and mechanical requirements, contact Jean Bonin, *SOGERST*, 2020 University St., 14th floor, Montréal, Québec H3A 2A5. Tel. (514) 845-6141. **Reprint Permissions:** Abstracting is permitted with credit to the source. Libraries are permitted to photocopy for private use of patrons. Instructors are permitted to photocopy isolated articles for non-commercial classroom use without fee. For other copying, reprint or republication, write to Manager of Canadian Member Services at IEEE Canada. Printed in Canada. Postage paid at Montréal Canada. **Postmaster:** Send address changes to *IEEE Canadian Review*, 7061 Yonge St., Thornhill, Ont. L3T 2A6 Canada.

Public Awareness of Science and Technology

by Dr. Tony R. Eastham
Director, IEEE Canada

A recent study has shown that the public awareness of science and technology is worryingly low. This, and the falling numbers of secondary students seeking entry to university and engineering programs leads to concerns that Canada does not have an adequate science and technology culture and that our universities and colleges will not be graduating sufficient competent engineers, scientists and technologists to remain industrially competitive towards the late nineties and beyond.

We have a problem:

- over half of Canadians do not know that electrons are smaller than atoms;
- close to half (49%) do not know that it takes a year for the earth to go around the sun;
- about a quarter think that sound travels faster than light;
- over half could not name a single Canadian scientist or a single Canadian achievement in science;
- Only four in ten were able to identify coal-fired plants as a source of acid rain, and about the same number consider scientists "dangerous" because of the knowledge they possess.

Dr. Edna F. Einsiedel of the University of Calgary recently discovered these and other results as part of a survey which included a basic science knowledge quiz. Her study "Scientific Literacy: A Survey of Adult Canadians", supported by grants from the Social Sciences and Humanities Research Council of Canada and from Industry, Science and Technology Canada, was reported at a recent meeting of the Royal Society of Canada. Representatives of most of the scientific and technological societies in Canada, including your Director, met to discuss "Communicating Science: Why and How" in Ottawa last March.

It was agreed that we, as a country, do have a problem. We can take some comfort from the fact that knowledge of and enthusiasm for science is declining in several other technologically-developed countries. However, unless we can guide our population to a better appreciation of science and technology, we are particularly vulnerable to a long-term downturn in our industry, economy and standard of living.

What to do? It was generally agreed that, while we cannot neglect the current workforce, we must focus attention on our schools. We must examine carefully and critically the expectations and role models to which children are exposed. We must strive to ensure that science teachers are themselves "scientifically literate" through improved programs in our teacher training colleges. We, as parents, must not give negative signals to children who express an interest in a scientific career. We must encourage more girls to think about science and engineering programs in universities.

What can we, as engineers, do? How about offering a show-and-tell lesson on your favourite science theme. At the Ottawa meeting, we were urged to encourage our members to offer such a talk to local Boards of Education and to Principals of both primary and secondary schools. In the Science-in-Schools workshops, the society directors and president played class and experienced two such lessons – on the physics of waves and earthquakes, and on the evolution of fossil fuels.

Needless to say, such lessons must be visually appealing, interactive and participatory – our middle-aged class found them most stimulating.

Scientific literacy cannot be improved overnight. We need to set a long-term goal. We all can help – in our homes as parents, in the schools as teachers and in the workplace as engineering and technology communicators.

An Expression of Faith in Our Profession

On December 6, 1989, tragedy stuck the student population of the University of Montreal's École Polytechnique in Quebec, Canada. Fourteen young female engineering students were the victims of an assassin – many others were wounded and terrorized. President Emerson Pugh, in a letter to Dean Corville, expressed "our horror at the violence which brought so much sorrow to so many families and to your community."

Nathalie Provost, one of the injured students who survived the massacre, gave a remarkable endorsement of the engineering profession in response to a media interview. From her hospital bed, she dismissed the temptation to speak of her own physical pain or the mental anguish of the families and friends of the young women whose careers had been snatched away in an instant. I am sure she felt all of those things, but more compelling for her in those trying moments was a need to reassure the public and particularly those considering the engineering profession as a career to not let this incident deter them from that goal.

Here are her words:

"I ask every girl in Québec, and everywhere in the world, who wants to be an Engineer to keep that idea in their mind because engineering is a great profession.

I told him that we were just women who study in engineering – we don't fight to prove that we are women – we don't fight to prove that we are better than men.

After I told him this, he may have tried to say something, which I didn't understand, and he started shooting."

We, in the IEEE, often wonder about the interest students have in pursuing engineering as a career. Nathalie's simple but courageous message should dispel some of our concerns.

Wallace S. Read, President, Canadian Electrical Association

The Need to Increase Industrial R&D in Canada

Where do we want to be as a nation and how do we get there?

by Roger A. Blais, O.C., Eng.
Professor of Industrial Innovation
École Polytechnique de Montréal

An increase in the level and effectiveness of industrial R&D in Canada is of paramount importance in order to ensure our economic and social future. This is NOT a motherhood statement. It is a FACT based on the harsh realities of the global economy and the extreme competitiveness in the production of high quality goods and services in a world marked by rapid and unrelenting technological change.

Markets around the world are becoming increasingly homogeneous. The costs of physical capital and skilled labor are on the rise and converging in industrial countries. However, as I have argued elsewhere[1], the relatively high cost of money in Canada is particularly detrimental to long-term investment such as R&D. As shown in Figure 1, the Japanese can afford to wait twice as long as Canadians to reap equal benefits from R&D. Added to this financial advantage is Japan's strategy of betting on the long term rather than mostly on the short term as we so often do in Canada.

My purpose here is to draw attention to some of these issues, some of which have already been introduced by Maurice Huppé in a guest editorial last March in this journal.

Too Little Industrial R&D

Everyone recognizes that in order to compete effectively in the international marketplace Canadian firms must be productive and innovative. Poor productivity still plagues Canadian industry: according to the U.S. Department of Labor (1989), from 1978 to 1988 the growth in manufactured output per employee has grown by only 11.1% in Canada compared with 16.5% in Sweden, 18.8% in West Germany, 19.1% in Great Britain, 23,4% in France, 23.8% in Italy, 35.3% in Japan and 71.6% in South Korea.

Industrial productivity and innovation are closely linked to industrial R&D and to technology transfer. In Canada we are weak on both counts. For example, Canada's gross expenditures on research and development (GERD) are only 1.3% of gross domestic product (GDP) compared with nearly 3.0% in Japan, West Germany, Switzerland and Sweden, and about 2.5% in the U.S.A., France, Netherlands and Great Britain. After hitting a "high" of 1.43% in 1986, we are now back to the level of 19 years ago when international competition was much less fierce than it is now and the demand for high value-added goods and services was very much smaller.

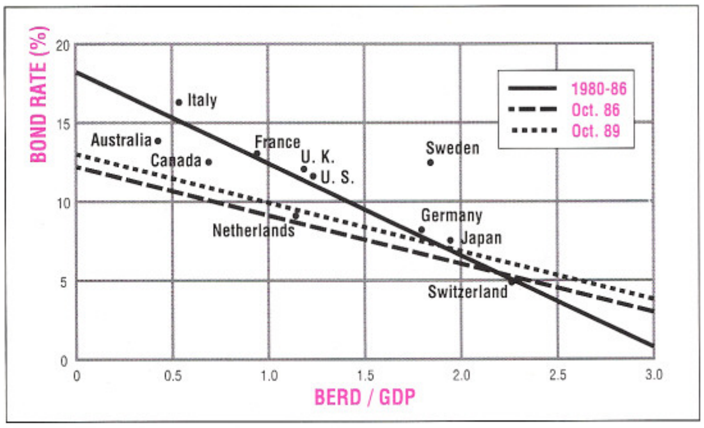

Figure 1 Relationship between business expenditures on R&D (BERD) and long-term bond rates, average for period 1980-1986 and for October 1986 as well as October 1989.

Studies by the Economic Council of Canada have shown that Canadian industry has been slow to benefit from technology transfer. In fact, it has often taken an inordinate amount of time for technologies to move just from one Canadian province to another. This problem is particularly acute in small firms. In order to alleviate this, the National Reseach Council of Canada has now embarked on an ambitious technology transfer program. But without real industrial leadership, the situation will not improve much.

I think that the main reason why Canadian industry, both indigenous and foreign owned, has not invested more in R&D is simply that it did not have to do it. In other words, it could get by without it. But this is no longer the case. For example, even our primary industries, which have contributed so much to our export strength and to our economic well-being, are seriously threatened by foreign competition, particularly from low-wage and less environment-conscious countries.

In the services sector, where two-thirds of all jobs are now concentrated, the need for more R&D is also felt. There, too, the development and application of new technologies are required in order to curb costs and increase productivity.

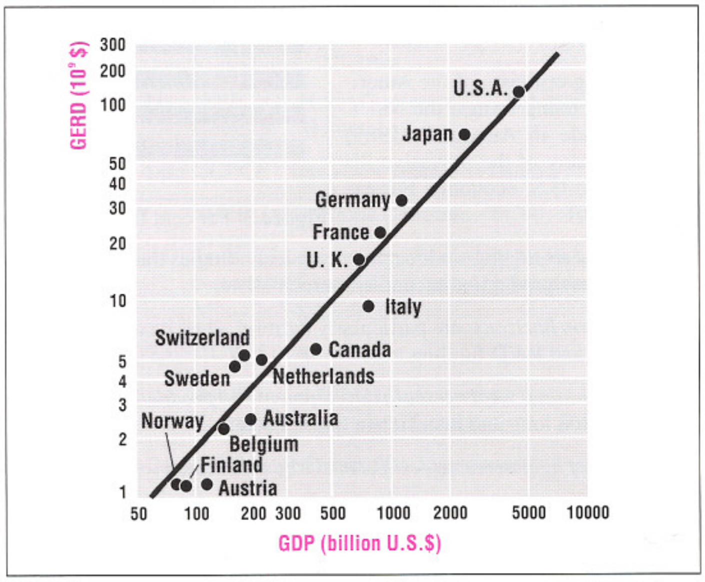

Figure 2 Log-log correlation between GERD and GDP; selected OECD countries, 1987.

A New Economic Paradigm

The world has changed tremendously during the past 25 years. As British economist Christopher Freeman now argues, we are seeing the emergence of a new techno-economic paradigm, one that combines system innovations, affecting the entire economy, with common sense incremental innovations brought about by technical managers and shop floor personnel in the various industries.

The contrast between the "old" fordist approach and the new economic paradigm is striking:

Old approach	***New approach***
Energy intensive technologies	Information intensive technologies
Standardized production	Customized production
Rather stable product mix	Rapid changes in product mix
Dedicated plant and equipment	Flexible production systems
Automation	Systematization
Simple firms	Network arrangements
Vertical hierarchies	Flat horizontal structures
Departmental divisions	Integration
Products with service	Service with products
Centralization	Distributed intelligence

The fastest growing industrial firms are using the new approach. While it would be ludicrous to merely copy the Japanese model of production without at the same time changing our mentality and value system, the spectacular technological developments and even more spectacular commercial achievements of Japan can be a source of deep inspiration. For example, the Japanese use the factory as a laboratory, with everyone contributing to the experiments to develop the best quality product. In the modern Japanese model, the firm is an innovative and dynamic organization that is continuously learning. Collaborative research networks add to the output of individual R&D laboratories, and the capital markets are geared not only to short-term but also to long-term investments in technologies. The friendly takeover of Lumonix, an Ottawa-based laser company, by Sumitomo, and that of Moli Energy, a Vancouver company specializing in rechargeable Li-battery cells, by Mitsui & Co., the giant Japanese trading company, are vivid illustrations of the Japanese industrial philosophy. One of Canada's biggest economic woes is the fact that virtually the only investors who are willing to put up risk capital to build enterprises here are foreigners or governments.

In a scathing criticism of the American way of doing things, the M.I.T. report "Made in America" (1989) describes many of the pervasive ills plaguing the U.S. economy. For example:

- *Outdated strategies:* undue reliance on technologies that are past their peak, mass production mentality, parochialism.
- *Short-term horizons:* are particularly harmful when it comes to capital markets and R&D funding.
- *Organizational weaknesses in development and production:* lead times that are too long and insufficient quality control.
- *Neglect of human resources:* particularly with regard to education and training.
- *Extreme individualism:* failure of cooperation.

In Canada the situation is not better. Clearly, structural change and a greater investment in industrial R&D are needed to ensure Canada's competitiveness in world markets.

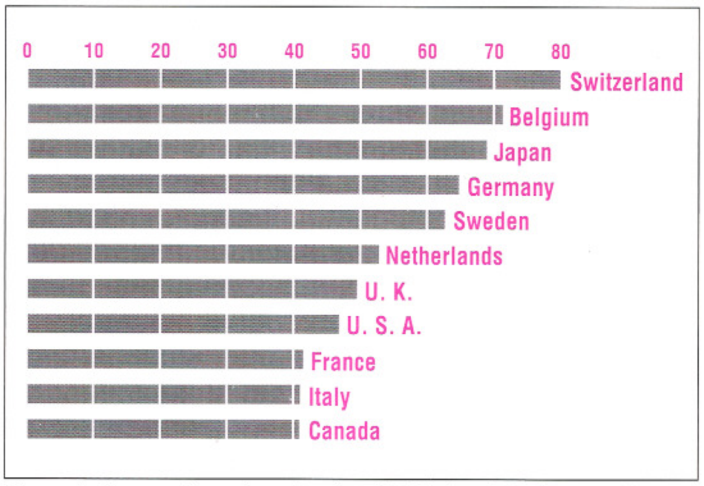

Figure 3 Per cent financing of national R&D by the industry, 1987

A Realistic Target for the Canadian R&D Effort

While R&D is only one of many factors affecting the performance of our industries in world markets, it should nonetheless be a determining factor in Canada's future success if it is well targeted and managed.

What should our national R&D level be? In 1976, the Honorable Judd Buchanan stipulated that the objective of his government was to raise the national level of R&D from 1.0% to 2.5% of gross domestic product (GDP) over the following five years. As I have indicated, the highest level reached was 1.43% in 1986 and the predicted figure for 1989 is 1.28%, close to that of Italy. With Prime Minister Mulroney having restated recently the national objective of 2.5%, a re-examination of that goal appears in order.

The first rule is that our gross expenditures on R&D (GERD) be proportional to the *size* of our economy. As shown in Figure 2, there is clearly a "massification" effect in GERD versus GDP. The larger the economy, the larger the proportion of GDP spent on R&D. For example, the big economic powers are spending between 2.5 and 3.0% of GDP on R&D and the smaller economies proportionately less. In the case of the OECD countries shown in Figure 2, the correlation is very high, in the order of r^2=0.95.

On this basis, just to be in line, Canada would have to spend US $2.4 billion more on R&D, i.e. we would need to move up by this amount on the graph to reach the regression curve.

The second rule is to consider the *type of economy* we have. Most primary industries in the world have long product life cycles and they spend relatively little on R&D. To use comparative figures, it is deemed appropriate to subtract from the Canadian GDP the portion relating to forests and mines which have very low R&D intensity, or 6.6% of US $411 billion, i.e. US $27 billion. Agriculture (3.0%) is not subtracted as it is important in most OECD countries as well. Thus, by moving Canada's point horizontally to the left by US $27 billion on the chart in Figure 2, it can be seen that an extra US $1.8 billion of GERD would be needed to reach the regression line. With this additional capital, the "normalized" rate of GERD versus GDP would have reached 1.92% in 1987 and not 1.35% as was actually the case.

The third rule is to have Canadian industry *fund a much larger proportion* of the total national R&D, an amount at least comparable to that of our trading partners (who are, in fact, our industrial competitors). As shown in Figure 3, the proportion of R&D financed by industry in Canada is only 42% compared to 80% in Switzerland, 73% in Belgium, 69% in Japan, 66% in West Germany, and 63% in Sweden. In the U.S., industry contributes 47.4% but this amount is considerably increased by the huge government contracts in defence and aerospace which help U.S. industries develop many new technologies – from A to Z – thereby enhancing their position in world markets.

In 1989, Canadian industry spent an estimated C$3.33 billion on R&D when the % GERD/GDP fell to 1.28%. If Canadian industry had contributed its fair share to the national R&D effort, let us say 66% of the total as is so often the case in many advanced countries (cf.Fig.3), then industry should have spent C$4.52 billion more on R&D in 1989 to ensure its own competitiveness, viz.:

$$3.33 \times \frac{1.92\%}{1.28\%} \times \frac{66\%}{42\%} = \text{C\$7.85 billion}$$

Although this increase in industrial R&D appears at first glance to be exorbitant, it is really not, considering the level of R&D investment made by our industrial competitors. However, the big question is what will bring

Canadian industry to invest twice as much in R&D just to be proportionately at par with its competitors?

A fourth rule is to consider Canada's R&D position on a *sector-by-sector basis*. Indeed, global goals such as x % GERD/GDP, or so much R&D funding by industry versus government, are difficult to grasp and implement. It is in each individual sector that the competition is felt most keenly and it is there that international comparisons in % GERD/GDP ought to be made.

It is encouraging that Industry, Science and Technology Canada is now working in this direction. Not only is there a need to align the statistics of industry-funded R&D by sector but also to discover and correct the other impediments to Canada's competitiveness in world markets. One of these is Canada's growing shortage of qualified scientists and engineers with good training and real appreciation of the international marketplace and of the way it works.

Conclusion

One of the most perplexing issues for our leaders is how to manage technological change in transient environments characterized by fast-moving technological targets. Industrial R&D, although important, is not a panacea for correcting Canada's weak position in high-technology markets. Obviously, what we need is an integrated and balanced approach to the *strategic management of technology*. Indeed, as the Assistant Secretary of the U.S. Department of Commerce has said:

"Advancing technology has become a primary driving force for all world economies, and effective management of this function will determine the rise and fall of nations as well as of industries and individual businesses. Management, by definition, has now become the management of technologically driven change, marked by the progressive collapse of product and process life cycles, previously measured in decades, but now more often in two to five year periods."[2]

New technology has become a primary energizing force in the economic revitalization of nations. In the U.S. it is credited for more than 40% of GDP and 50% of the increased productivity. Nowhere has this technological revolution been more spectacular than in Japan. South Korea and other Asian countries are now quickly entering the race. The most progressive countries are all investing heavily in industrial R&D because of a major change in the prevailing economic paradigm.

These major shifts call for LEADERSHIP, particularly from planners and decision-makers in industry. One important aspect of leadership is VISION: where do we want to be as a nation and how do we get there – that is the question.

[1] Blais, R.A. (1989) "The Case for a Major Increase of Industrial Research in Canada," Corporate-Higher Education Forum, Seminar on Private Investment in Research, Toronto, Dec 6, 1989, 45 pages.

[2] Merrifield, D.Bruce (1988), "Industrial Survival via Management Technology" Journal of Business Venturing, Vol. 3, No.3, pp. 171-185.

IEEE Canada Shapshot

Ray Findlay has done it again!

We had come together for the Central Canada Council Training Meeting, Gordon Chen, John Cortes, Julian Egglestone, Steve Swing, and Pam Woodrow during one of Ray Findlay's Professional Development Exercises. The task: "How to Make our Section Great".

We knew what to do, we had just been through it. First, we brainstormed for ideas, no matter how "way out." Second, we put them in priority order. Finally, we identified a method to achieve our goal.

We selected to achieve an enthusiastic and involved membership.

We identified our resources as: Region 7 Office, Region 7 Financial reserves, Meeting facilities, Personal contacts, Newsletters, Retired members, Student members.

Next we identified our problems, which included: Apathy, Perceived reputation, Diversity of members' needs, Distances of travel.

After discussion, and dissension, we moved on to our roadblocks. In our case, there were:

- We can't please all the people all the time
- Time demands of executives and members
- Little industry support
- We cannot reimburse executive members for their time and expenses.

We came up with this plan:

1. Use personal contacts by executive members to poll a cross-section of the membership for their needs and wants. With these identified, enlist their help to implement them.
2. The executive committee then radically changes existing programs to suit these needs.
3. Use resources to implement new programs, then use personal contacts, improve newsletter and get students to advertise.
4. Follow up with awards/prizes and recognition of Section heroes with "warm fuzzies" all around for the good work done.
5. Go back to No. 1 and start again.

Naively, we presented this as requested to the Council group, feeling that this was a reasonable way to improve Section affairs, but Ray was not finished. No, Sir! "I want you to write it up for the Canadian Review" he said. Well, here it is!

John Cortes and Julian Eggleston - London Section.

IEEE Conferences in Canada - 1990

May 13-16	IEEE 6th Semi-Insulating Materials - Toronto
June 3-6	IEEE International Symposium on Electrical Insulation - Toronto
June 11-14	IEEE Conference on Precision Electromagnetic Measurement - Ottawa
June 19-21	IEEE Industrial Automation Conference - Toronto
June 19-21	IEEE ESMO/Construction 90 - Toronto
June 27-28	Canadian Conference on Engineering Education - Toronto
July 6-7	IEEE WESCANEX 90 Telecommunications for Health Care - Calgary
August 12-14	33rd IEEE Midwest Symposium on Circuits & Systems - Calgary
August 14-16	5th Canadian Semiconductor Technology Conference - Ottawa
August 20-24	IEEE 36th Holm Conference on Electric Contacts - Montreal
September 4-6	CCECE "Ten Years to 2000" - Ottawa
October 4-7	IEEE 3rd Sections Congress - SC90 - Toronto
October 11-13	1st IEEE International Workshop on Photonic Networks, Components and Applilcations - Montebello, Quebec
October 21-23	CCVLSI '90 - Ottawa
October 22-24	4th Biennial IEEE Conference on Electromagnetic Field Computation - Toronto
October 23-26	IEEE Inter Comm 90 - Vancouver
October 25-26	2nd IEEE Alberta Conference and Exposition on Power Quality Issues - Edmonton

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Technology, R&D and Government

If technology is strategic to the future of our nation, perhaps we need to pay more attention to how it comes into being.

by Richard J. Marceau
Secretary, IEEE Canada

Technology and national strategy

Thanks to its own efforts and those of its principal economic partners, Canada has long had ready and economical access to almost any technology necessary for its development. However, as many nations enter into a process of rapid technological evolution, Canada finds itself in a world of increasingly fierce competition in every sphere of activity including technology. In view of the importance of technology to a nation's present and future wealth and influence, how can we, as a nation, react to this changing environment?

Technologie et stratégie nationale

Grâce à ses propres efforts ainsi qu'à ceux de ses principaux partenaires économiques, le Canada a depuis longtemps accès aux technologies réquises pour assurer son développement. Toutefois, plusieurs pays amorcent un processus d'évolution technologique rapide: le Canada se retrouve dans un monde de compétition féroce où toutes les sphères d'activités sont touchées, en incluant la technologie. Étant donné l'impact de la technologie envers la richesse et l'influence d'une nation moderne, comment devons-nous réagir, en tant que nation, à cet environnement évolutif?

In our world today, few nations will deny the strategic importance of technical expertise and advanced technological means coupled to an abundant supply of natural resources and a powerful financial infrastructure. The lack of free access to any one of these elements not only signifies dependence in the short term but vulnerability in the long term, whether seen from a political, economic, social or any other perspective.

Canada is a nation blessed by the relatively easy access to all of these elements. Nevertheless, when considering technology, it may not be so obvious that this should be taken for granted. Indeed, examples abound from recent times, primarily in relation to East-West or North-South relations, where various types of technology have not been made freely available, usually for reasons of national security. Nuclear or nuclear-propelled weapons systems immediately come to mind, but many other technologies such as more conventional weapons systems, high-precision numerical machine-tools, supercomputers and even some personal computers have seen their access severely restricted.

As other nations strive towards a higher technological base and attempt to protect whatever competitive edge they have, the access to new technology may change. In the same way that the controlled access to a national economy is one of many tools used by many nations to achieve strategic aims, the pressure to control access to technology as a lever of national economic policy may increase, not diminish.

In the past two centuries, technology has rapidly evolved to become a powerful economic vector for private enterprise, fueling social change, transforming the world we live in. Technology now stands at the very base of a nation's present and future wealth and influence, not only because an advanced technological base represents its potential to multiply the productivity of individuals, but also because it represents its capacity to continue this multiplying effect through future generations of technology.

Due to the strategic importance of technology, it is incumbent upon a nation's government to provide the leadership, nurture, stimuli, and environment whereby technology progresses and stimulates scientific breakthroughs into new areas. Notwithstanding the accelerated pace of technological evolution of the past three or four human generations, many are tempted to believe that the great scientific breakthroughs are a thing of the past. In fact, we have barely begun to understand the universe about us.

For Canada to maintain, if not increase, its relative economic weight in the rapidly changing world arena, limited as it is by its small population, it must actively search for ways to continue to amplify the efforts of its people. Technology, in this regard, must be seen as an instrument of national policy, wherein the necessity to reinforce the existing high technology infrastructure and governement technological policies.

Beyond the practical limitations of governmental financial restraint, how does one translate the concepts of nurture, stimuli, environment into a practical approach? What specific objective should be pursued? And is research and development the *only* cornerstone of a national policy on technology?

Technology and R&D

R&D is a familiar catchword that means different things to different people. Though one can easily associate the term "research" to a quest for understanding or new knowledge, "development" has been seen to describe anything from building a laboratory prototype to establishing the groundwork for new markets. In order to fill this gap, other terms, such as "demonstration", "innovation" and "qualification", have arisen. But regardless of how one defines the exact meaning behind the words, development is linked in some way to the application of knowledge. One intuitively senses that R&D represents the first few stages of a larger process involving the successful introduction and commercial exploitation of successive generations of technologies.

To make this process effective requires an understanding of how knowledge and technology interact, resulting in the advancement of both. Inventors, engineers, innovators or researchers will happily point out this iterative process as its relates to specific projects. And as one examines the macroscopic interaction between technology and knowledge on a longer time scale, they seem to combine, from seemingly unrelated fields, through apparently improbable scenarios, to advance the technological base of a nation to new generations of technology and new knowledge. In other words, the macroscopic process of technological evolution is a closed-loop process.

As every engineer has learned at one time or another, open-loop systems are inherently unstable. A national technology policy hinged solely on R&D, ignoring how it interacts with the remainder of the process, is like inputting a process whose output and feedback are not being monitored or controlled downstream. There is a very real danger that no output emerges: critical paths

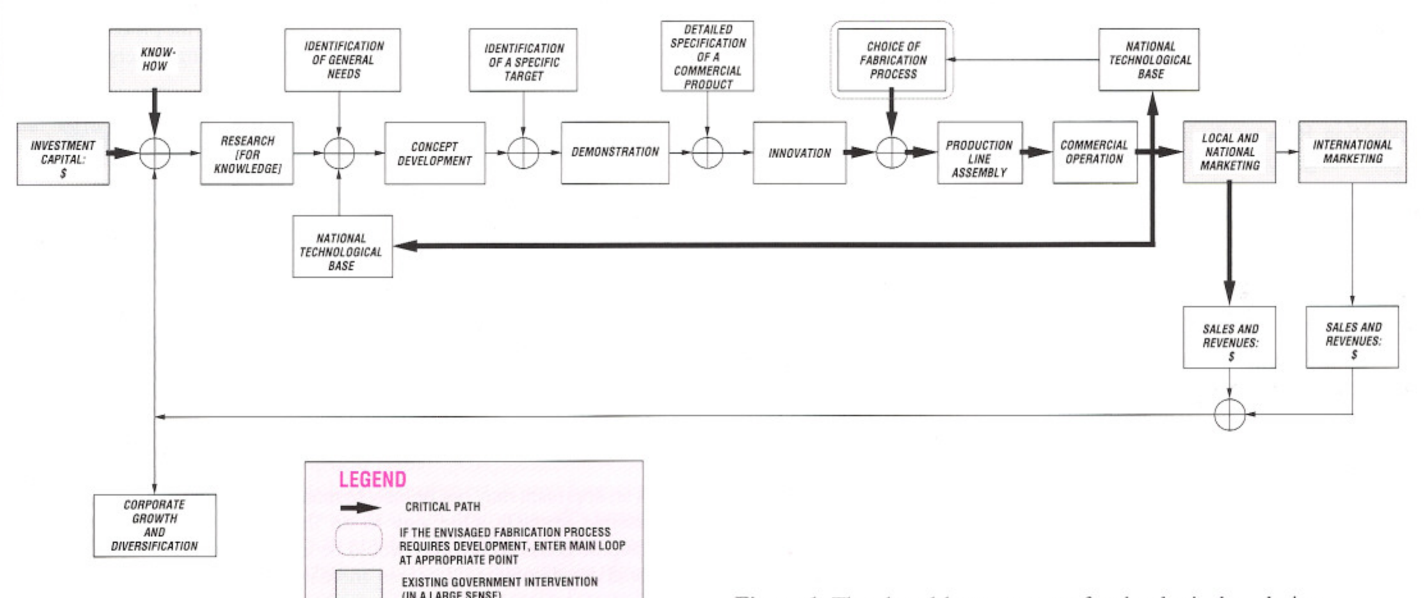

Figure 1 The closed-loop process of technological evolution

exist at several points in a loop, not just at the input stages where we find R&D. Let us examine this closed-loop process more closely, as illustrated in Figure 1.

The Process of Technological Evolution

As a working hypothesis, let us define R&D as having, at any one time, one or several of the following objectives:

a) The quest for knowledge;

b) The training of researchers, engineers, innovators or scientists;

c) The active prospecting of new technologies;

Establishing the basic concepts for:

d) the improvement of existing products or processes;

e) the introduction of new products or processes.

In Figure 1, one can directly relate the stages of *Research (For Knowledge)* and acquiring *Know-How* to a) and b) respectively, while d) and e) correspond to the *Concept Development* stage. Item c) can belong to either one of the three, according to how loosely it is coupled to specific needs.

Let us momentarily examine the impact of the availability of different types of technology to the initial R&D stages. The particular path of development taken in specific instances is heavily influenced by a society's present technological base. The higher the level of this base, the more ambitious the concepts which can, in one form or another, find their way to the marketplace. These in turn contribute to incrementing the base, which facilitates the emergence of new knowledge, from which springs further development. A mutual feedback consequently develops between knowledge and technology, resulting in a closed-loop system. And the enrichment of the technological base is the key to understanding the closed-loop nature of the process.

Downstream of the process, beyond the *Concept Development* stage, one targets a specific application which leads to the *Demonstration* of a scale- or life-sized prototype under real-life conditions. Much detailed design and fine-tuning follows even with highly successful demonstrations. If the technology is a specific product (hardware or software), a detailed commercial specification relating to the optimization of unit cost, quality and efficient manufacture represent the main challenges of the *Innovation* stage. If the technology is a process, the challenge is to implement the process in such a way that unit cost and quality are once again optimal. What then follows is the actual *Construction* of the production line and its subsequent *Commercial Operation*.

For an incremental advancement of the technological base to be permanent, the economic self-sufficiency of the means of production is essential until the product or process is no longer competitive, can be replaced by something better or is no longer socially or environmentally acceptable. Of course, economic self-sufficiency generates profits which are the sinew of further activity.

When applied to specific cases, some of the stages illustrated in Figure 1 take on more importance than others. In fact, in an effort to reduce lead time to product introduction, much effort has been directed to reducing the time required at each step. Powerful and reliable simulation can even permit the short-circuiting of certain stages altogether. However, each stage represents a specific need in the process, whether it exists implicitly or explicitly.

Critical Paths

The various government levels bring considerable support to different points in the process. For instance, many existing measures:

a) ensure the existence of a comprehensive education system, which supplies expertise and know-how;

b) provide partial or complete funding for many pure and applied R&D programs and projects;

c) stimulate partnership between industry, university and government;

d) facilitate the availability of investment or venture capital for job-creating projects of varying degrees of risk;

e) encourage the purchase of products from companies based locally or nationally;

f) promote the availability of Canadian products in foreign markets.

At first glance, one may be tempted to ask if there is anything left to be done. However, there is a weakness: these individual measures are not orchestrated as a coherent whole in tune with the technological process. The access to one set of measures and the consequent success of a particular stage in the process by no means translate into eligibility to another set of measures, or that appropriate measures even exist to exploit or weather the next stage. And need it be said that many obstacles must be overcome before a new technology is economically self-sustaining?

But when do obstacles become critical paths? One can suppose that obstacles which are not under direct organizational control can become critical paths. Of course, technology itself may present insurmountable obstacles. However, once a specific project is considered feasible and given the green light, one must assume that all technological task forces, pitted face to face against unforgiving matter, are on an equal footing.

According to this definition, there are three critical paths to the process, two being at the point of entry: Availability of personnel having the necessary knowledge and expertise, and Accessibility of financing. The third critical path lies closer to the process output: inasmuch as R&D requires funding, the greatest financial risk lies in the generally far more considerable capital investment required to construct, commission and start-up new means of production. Between the initial go-ahead and the time a new production unit is generating a cash flow in line with its financial obligations, the fear of uncertainty and exposure may stifle the initiative to go with an otherwise promising technology, unless one can convince everyone concerned in the process that the risk is worth their while.

Incentives to the Process

Of course, this is far more simple to say than to do. On the one hand, motivation, though a necessary condition, may not always suffice to carry the day. On the other hand, nor are unlimited financial means a guarantee of success. However, one must recognize that motivation has the intangible attribute to provide far more margin than can be quantified *a priori,* if the proper incentives exist.

A national commitment to incrementing the technological base is precisely the type of objective that is best addressed by a global policy on technology. By means of a comprehensive set of incentives that reinforce the critical paths of the technological process, an appropriate policy can galvanize the physical and psychological energies of all those contributing to the process; the researchers, engineers, inventors, innovators, who will champion a project; the middle-managers who believe that the return is worth the investment; the high-level decision-makers who see new technology fueling growth and generating higher profits; the corporations that wish to increase their competitiveness or diversify into new areas; and, lest we forget, the production workers whose toil will permit a new technology to see the day.

One way to generate motivation is to provide contributor-specific incentives at every stage of the process. To ensure the eligibility to these incentives, one need only enter the process by investing in research, concept development, prototype demonstration, or any combination thereof. Four potential types of incentives, driven by self-interest, can thus be identified:

1. a corporate incentive;
2. an incentive at the individual level, for each employee involved in an individual project;
3. an incentive that will stimulate the *purchase* of products emerging from the incentives' program by those themselves engaged in the process: for instance, using products having emerged from the program as building blocks of new technology in the upstream stages (i.e. R&D, Demonstration, Innovation) or purchasing and exploiting such products when constructing new factories;
4. an incentive that will stimulate the *sale* – at large – of products emerging from this program.

Measures 1 and 2 directly target the motivation of those with a vested interest in the success of a new technology (i.e. a company and its employees) while attempting to reduce obstacles at the point of entry. At the output end, measures 3 and 4 will accelerate the purchase, acceptability and credibility of new products and help reinforce the competitive position of more traditional products emerging from a new process. In addition, the latter measures will encourage those having invested most heavily in time, effort and financial resources: a psychological intangible which may help smooth over some difficulties. Finally, corporate incentives provide margin for an enlightened company to reward its employees even further when the payoff appears.

A concrete example of each of these could be as follows:

1. in addition to all other incentives presently available at the point of entry, a reduction or absence of corporate income tax on all revenues associated with a new production unit for the first few years of commercial operation; for example two years.
2. a reduction or absence of personal income tax for the first few years of production (again, for example, two years) for all employees involved in the risk of realizing a new production unit, from R&D all the way to commercial operation;
3. a reduction or absence of sales taxes for 2 years associated with the *purchase*, by those who are themselves engaged in the process of building means of production, of earlier products having emerged from the process;
4. a reduction or absence of sales taxes for 2 years associated with the *sale* of products from new means of production emerging from the process.

As a whole, by encouraging the rapid utilization of locally emerging technologies and the reinsertion of new "technological building blocks" in downstream developments, one generates interest to enter the process and a technological momentum arises as a result of the closed-loop process. This momentum drives the rise of the technological base, which, in the long run, increases the overall productivity and competitivity of industry.

At first glance, one may suppose that such measures are unthinkable in this age of increasing national deficits. However, one can also suppose that much of the additional economic activity generated by virtue of the implementation of such measures would not have existed otherwise.

Such an approach may not be easy to manage, but this must not appear as an impossible obstacle. One way to do this would be to create exclusive, geographic zones where they would be in effect in such a way as to favour regional development. Of course, there may be other ways. But the bottom line is that something must be done.

Conclusion

Technology is of strategic importance to the future of our nation. Though support of R&D is essential, the emergence of new technology is a closed-loop process: to drive this process effectively and advance the national technological base, a national technology policy must not only provide incentives at the input (R&D) end but at all critical paths throughout the process.

The basic principle behind such a policy must be motivation. Everyone in the process, at every level, must find some incentive to deliver his or her best, at all times. And when government provides leadership, industry plays its part. Otherwise, individual, heroic efforts aren't enough to maintain our competitive edge in the world economic arena. It's a question of national strategy.

Évaluation non destructive par thermographie infrarouge

Des méthodes passives et actives pour sonder la matière sous la surface.

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Un survol de la vision infrarouge

De nouvelles méthodes employant la vision infrarouge (aussi appelée thermographie) sont disponibles pour l'inspection des matériaux et structures en milieu industriel. L'approche passive où l'on se contente d'observer les isothermes tels quels et l'approche active où l'on apporte une stimulation externe sont présentées de même qu'une courte revue des différents types de caméras et des exemples d'applications. De façon à pouvoir faire des comparaisons avec d'autres techniques plus conventionnelles d'évaluation non destructive (END), les avantages et problèmes de la thermographie infrarouge sont brièvement exposés.

A survey of infrared vision technology

New methods using infrared vision (also called thermography) are available for inspection of materials and structures in industries. The passive approach where the observation of isotherms is done without any externally applied thermal perturbation and the active approach where the part response is stimulated are presented along with a short review of the available infrared cameras and application examples. In order to compare with other more conventional non-destructive evaluation (NDE) techniques, the advantages and problems of infrared thermography are also briefly exposed.

De nos jours, dans le contexte d'un indispensable accroissement de la productivité, le contrôle de la qualité est devenu fondamental. Diverses méthodes d'évaluation non destructive des matériaux (ÉND) solutionnent bon nombre de problèmes d'inspection, citons ainsi les cinq techniques classiques que sont les ultrasons, la radiographie aux rayons X, les courants de Foucault, les pénétrants à colorant et les perturbations du flux magnétique.

Les techniques d'ÉND permettent pas exemple de détecter des anomalies, de découvrir des défauts non-conducteurs thermiquement tels des fissures, délaminations, décollements ainsi que la présence de matières étrangères sans atteinte à l'intégrité physique des composantes sous investigation.

Un outil très prometteur pour l'ÉND est la vision infrarouge aussi appelée thermographie infrarouge. Cette technique s'est développée à la suite de la commercialisation de caméras spécialement adaptées au spectre infrarouge. À la différence des images du spectre visible (plage de longueurs d'onde s'étendant de 0,35 à 0,75 μm) qui sont produites par réflection et différences de réflectivité, les images infrarouges (principalement les bandes 3-5 μm et 8-12 μm) sont produites par un phénomène d'émission propre et de différences d'émissivité. Les traitements d'images par ordinateur seront donc quelque peu différents des traitements traditionnels appliqués aux images du spectre visible. En infrarouge, on remarque ainsi un contenu spatial des images plus réduit, ce qui tend à simplifier l'analyse. Un avantage important et inhérent à l'usage d'une caméra lors de l'inspection est qu'on obtient directement une image de la scène observée par laquelle la correspondance avec la composante inspectée est plus aisée que pour une simple mesure ponctuelle, bref, "on voit ce qu'on mesure".

Themographie passive

La première loi de la thermodynamique expose le principe de la conservation de l'énergie et explique que tout procédé (industriel) consommant de l'énergie verra une grande partie de cette énergie transformée en chaleur (selon la loi de l'entropie). La mesure de température est donc un paramètre très important à mesurer et c'est d'ailleurs le principe de la thermographie passive qui teste les matériaux et structures à la recherche d'anomalies (défauts) qui se manifestent par des zones dont la température est anormale. Le travail de détection consistera à identifier ces zones. On retrouve notamment des applications en production, maintenance, médecine, évaluation du trafic routier, détection des feux de forêt, astronomie. Par exemple, la thermographie permet le contrôle des circuits imprimés par la recherche de soudures et de composantes défectueuses grâce aux échauffements locaux qui sont détectés. Le même principe de localisation d'échauffements anormaux prévaut pour la maintenance des installations électriques: transformateurs, isolateurs, disjoncteurs (fig.1)

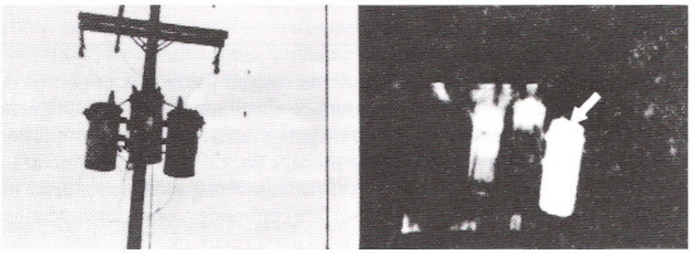


Figure 1 Thermographie Passive. La scène photographiée dans le spectre visible ne révèle apparemment aucun problème (à gauche). Par contre, l'image enregistrée dans l'infrarouge (à droite) montre qu'un des trois transformateurs (indiqué par une flèche) surchauffe, ce qui pourrait entraîner la panne d'un moteur triphasé branché à cette installation et alimenté soudainement en monophasé (figure reproduite avec permission, D. Stovicek *Power Transmission Design*, juin 1987, p.52).

Comme on le constate, les applications sont nombreuses. Les avantages de l'inspection par thermographie passive sont multiples. En maintenance par exemple:

- coût des réparations et temps perdu réduits grâce à la détection hâtive;
- usure réduite de l'équipement en réparant à temps;
- consommation d'énergie diminuée en remplaçant les composantes défectueuses;
- ruine fatale évitée;
- qualité obtenue accrue.

Thermographie active

L'approche active diffère de l'approche passive puisqu'une source thermique extérieure est nécessaire pour stimuler les matériaux à inspecter à la recherche

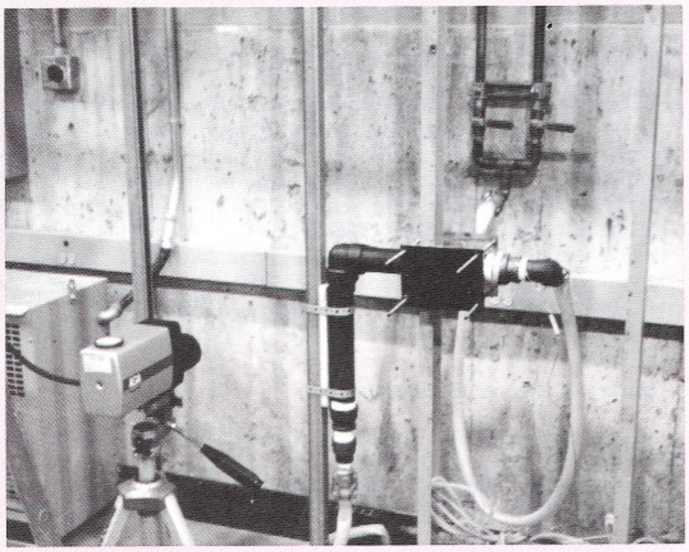
Non-Destructive Evaluation by Infrared Thermography: Passive and Active Methods to Probe Under the Surface

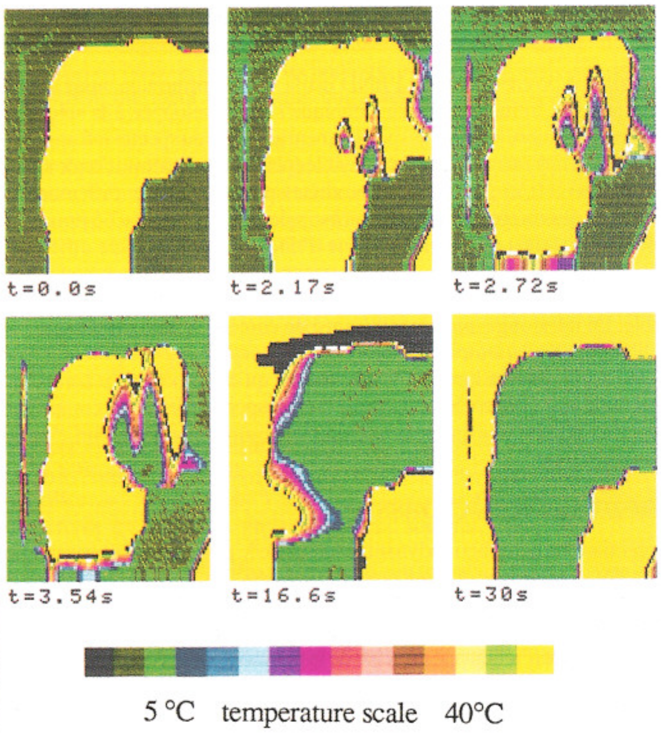
Quality control is fundamental in industry. Besides the more established non-destructive evaluation (NDE) techniques that are ultrasounds and X-ray radiography, new methods such as infrared thermography have emerged. NDE techniques allow, without causing damage to the inspected part, to pinpoint a large variety of abnormal behaviors and flows under the surface.

Temperature is a major parameter in numerous industrial processes. By measuring temperature differences on the surface, passive infrared thermography is capable of revealing abnormal operating conditions before catastrophic failure occurs. For instance, this technique finds applications in medicine, road traffic control, forest fire fighting, weatherization assistance programs, production, maintenance.

With active infrared thermography, a thermal pertubation is applied to the part in order to reveal the presence of non-thermally conducting defects such as delaminations, inclusions, disbondings, cracks under the surface. Contrary to the passive approach, a perturbation source is necessary because no temperature differential is apparent by itself on the external surface prior to the stimulation. Such stimulation of the part can be either cold or hot as long as a temperature differential is provoked, thus either a lamp heater or a cold air jet may be selected. Following the perturbation, the thermal front propagates by diffusion; the presence of a defect under the surface reduces the diffusion rate, causing localized temperature variations to appear on the external face after a time period which depends on defect depth. Those contrasts are recorded in image format by an infrared camera and, after proper interpretation and image processing, provide information about the buried defect.

Passive or active thermographic inspection technique has several advantages: it is fast, requires no contact, is harmless, easy to set up and to automate, even with access restricted on one side only of the part, and image interpretation is done without much difficulty. On the other hand, some problems remain, such as the cost of the equipment, the convective losses and variation of surface emissivity which may cause misinterpreted contrasts over the surface and, in the case of the active approach, the difficulty to obtain a short, strong and uniform thermal perturbation. Besides those difficulties, infrared vision is seen as a promising inspection technique and should become more widespread in the next 2 or 3 years with the availability of low-cost PtSi infrared detector arrays technology.





Active thermography. Experimental apparatus used for inspection of corroded pipes: the temperature of the water flow circulating inside the pipe is changed suddenly from 40°C (at t=0) to 6°C. The thermograms sequence show the thermal transition and a strong cavitation defect is revealed by the fast response of the thinner wall there.

Thermographie active. Montage expérimental pour l'inspection de tuyaux corrodés; la température de l'eau circulant à l'intérieur du coude est brusquement changée de 40°C (à t=0s) à 6°C. La séquence de thermogrammes montre la transition thermique et révèle une réduction locale majeure de l'épaisseur de la parois dont la réponse thermique est plus rapide.

d'éventuels défauts. Par thermographie active, on peut détecter les défauts dont les propriétés thermiques (surtout la conductivité thermique) sont différentes de celles du matériau sain; il s'agira par exemple de délaminations, décollements, fissures.

La source thermique peut être froide ou chaude, puisqu'il s'agit de susciter et de détecter des différences anormales de température par rapport à la température ambiante. On pourra ainsi employer la vibrothermographie où, sous l'effet de vibrations mécaniques (20 à 50Hz) induites de façon externe à la structure à inspecter, une élévation de température est produite par friction, précisément là où se situent les défauts (fissures).

Plus généralement, le principe d'investigation en thermographie active se réalise au moyen d'une impulsion thermique appliquée à la surface du matériau à inspecter. Une mesure de l'évolution temporelle de la température de cette surface est faite au moyen d'une caméra infrarouge et permet de révéler la présence de défauts sous la surface. Qualitativement, le phénomène est le suivant: la température du matériau change rapidement après l'impulsion initiale puisque le front thermique se propage par diffusion à l'intérieur. La présence de défauts sous la surface réduit le taux de diffusion, de sorte que les positions des défauts apparaissent en surface comme des zones de température différente, après que le front thermique ait atteint ceux-ci.

Tout le travail d'interprétation (manuelle ou automatique) consistera à détecter et à analyser ces zones de température différente pour identifier les défauts. Il faudra d'ailleurs recourir à une modélisation des transferts de chaleur pour l'étude quantitative rigoureuse. Des défauts plus profonds seront observés plus tard et avec un contraste moindre. En fait, le temps d'observation t est proportionnel au carré de la profondeur z et la perte de contraste PC est proportionnelle au cube de la profondeur:

$$t \approx (z^2/a) \text{ et } PC \approx (1/z^3) \quad (1)$$

où a = diffusivité thermique du matériau = k/pc où k est la conductivité thermique, p est la densité et c la chaleur spécifique du matériau.

Ces deux relations illustrent bien une des limitations de l'ÉND par thermographie active, les défauts détectables seront généralement peu profonds, les contrastes obtenus seront faibles. Une règle empirique très employée énonce que le rayon de plus petit défaut visible doit être au moins une à deux fois supérieur à sa profondeur sous la surface.

Le recours à une impulsion thermique pour la stimulation des composantes est très pratique puisque toutes les fréquences sont simultanément testées (spectre plat d'une impulsion de Dirac), au prix toutefois d'une sensibilité moindre. Une autre approche, par stimulation périodique où chaque fréquence est testée individuellement, est également possible. Sa mise en oeuvre est cependant laborieuse et trop longue en vue d'une inspection automatisée en temps réel.

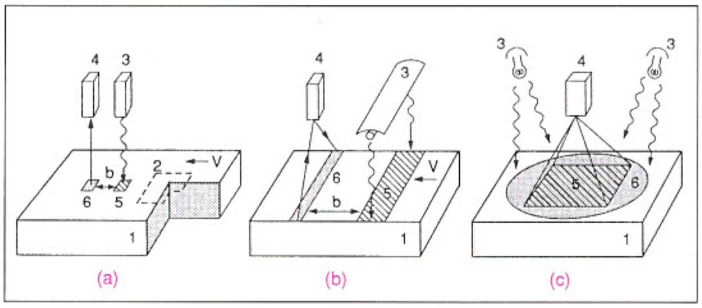


Figure 2 Différentes configurations d'inspection par thermographie active. Méthodes: (a) ponctuelle, (b) de ligne, (c) de surface. 1 - échantillon; 2 - défaut; 3 - source thermique; 4 - système infrarouge; 5 - zone chauffée; 6 - zone d'observation; v - vitesse de déplacement de la pièce inspectée.

Une autre façon de procéder pour la détection de fissures de surface consiste à faire propager le front thermique le long de la face externe de la composante. Le spécimen à inspecter est brusquement mis en contact avec une masse thermique de température différente (bloc de métal, sac rempli de liquide). La détection est possible lorsque la présence d'une fissure retarde la propagation. Cette méthode n'est toutefois pas vraiment pratique pour l'inspection répétitive en milieu industriel.

Dans le cas de l'approche active, différentes configurations sont possibles; la figure 2 présente les méthodes:

(a) ponctuelle (par point), chauffage par laser, arc au plasma; avantage: bonne uniformité de chauffage, mais nécessité de déplacement pour couvrir une surface et obtenir une image, donc une méthode plutôt lente;

(b) de ligne, chauffage par lampe infrarouge filiforme, jet d'air (froid ou chaud), fil chauffant; avantages: rapidité (vitesse d'inspection jusqu'à 1 m^2/s) et bonne uniformité à cause du déplacement latéral;

(c) de surface, chauffage par lampe incandescente, lampe éclair, balayage laser; avantage: analyse complète du phénomène puisqu'on obtient l'enregistrement de toute l'évolution temporelle de la température de surface, mais difficulté d'obtenir un chauffage uniforme.

Mentionnons aussi que si la pièce inspectée est à une température très élevée par rapport à la température ambiante à la suite des diverses étapes de sa fabrication, il peut être très judicieux et économique de recourir à une source de stimulation froide, comme une ligne de jet d'air, par exemple. En effet, un front thermique se propagera de façon identique qu'il soit froid ou chaud, ce qui compte vraiment c'est l'écart de température entre la source de stimulation thermique externe et la pièce à inspecter.

Deux méthodes d'observation sont possibles (fig.3):

(a) en réflexion, la source de chauffage et le détecteur sont situés d'un même côté de la pièce à inspecter;

(b) en transmission, la source de chauffage et le détecteur sont situés de part et d'autre de la pièce à inspecter.

En général, l'approche en réflexion est plus efficace pour détecter des défauts situés près de la surface chauffée alors que l'approche en transmission permet de détecter les défauts situés près de la surface arrière. De plus, l'observation en transmission n'est pas toujours possible (inaccessibilité) surtout dans le cas de structures complexes comprenant plusieurs épaisseurs (e.g. revêtements composites sur un nid d'abeilles).

La figure 4 montre une photo du montage expérimental nécessaire pour l'inspection par thermographie active de panneaux de graphite époxy employés dans l'industrie aérospatiale: configuration de surface (fig. 2-c), en réflexion (fig.3-a). Deux images, brute et après traitement, révèlent la présence d'une délamination circulaire sous la surface du panneau.

Matériel requis

Selon le problème d'inspection à résoudre, l'inspection sera passive ou active et l'instrumentation nécessaire sera quelque peu différente. Dans tous les cas cependant, il faudra une caméra infrarouge. Deux classes de caméras sont disponibles. Les caméras dont le détecteur est un tube vidicon pyroélectrique (détecteur thermique) sont très répandues à cause de leur coût abordable ≈ 15k$) Dans les détecteurs thermiques, la radiation infrarouge est absorbée et produit un changement de température au niveau du détecteur lui-même, la plage spectrale de sensibilité sera donc très large. Le thermomètre de verre fonctionne d'ailleurs sur ce principe. Propices pour la visualisation des zones chaudes et froides, ces caméras ne sont toutefois pas vraiment adaptées à l'analyse quantitative rigoureuse à cause des non-linéarités et non-uniformités spatiales de l'image.

Les autres types de caméras infrarouges sont construits autour de détecteurs photoniques. Dans ces détecteurs, l'énergie est absorbée et affecte l'état des atomes ou des électrons libres. Aucun changement de température n'étant nécessaire, le temps de réponse des détecteurs photoniques est plus rapide que

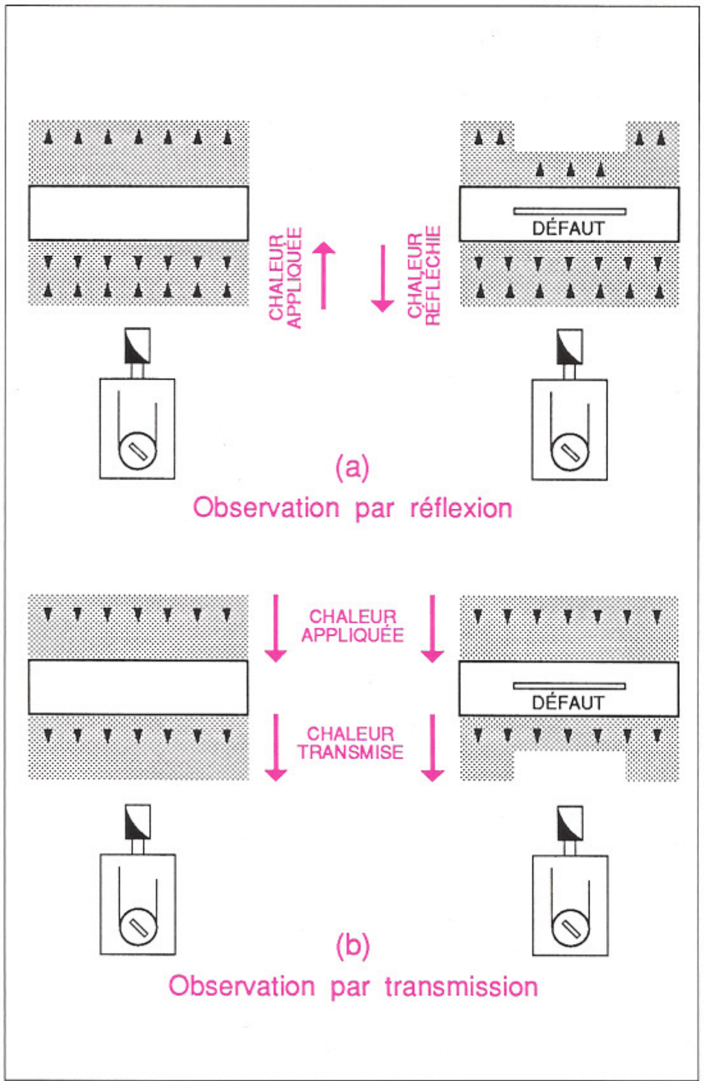


Figure 3 Méthodes d'observation (a) par réflexion, (b) par transmission.

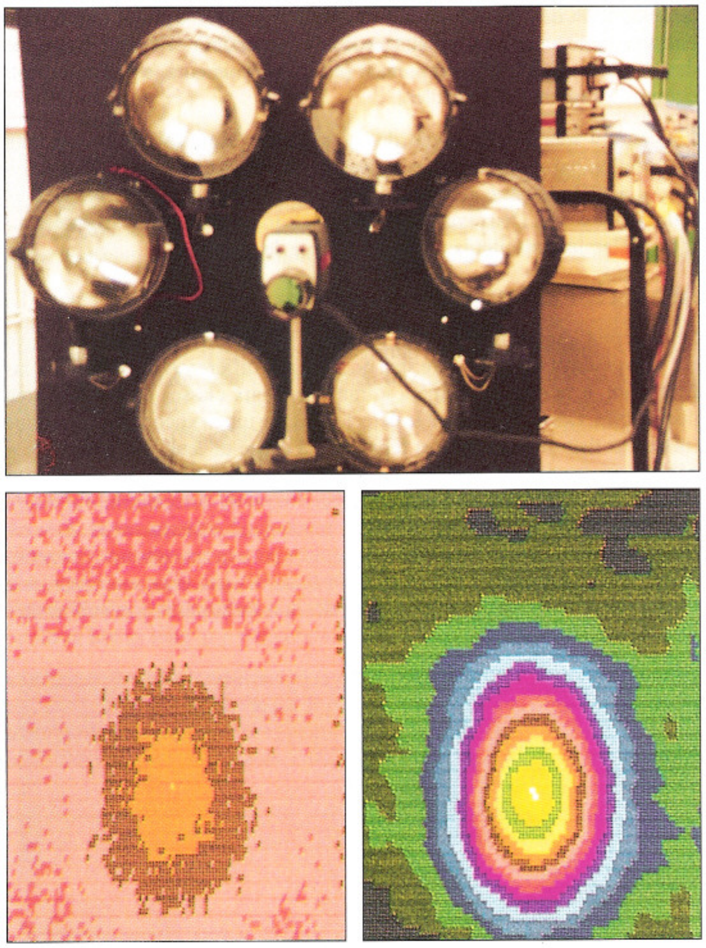


Figure 4 (a) Montage expérimental pour l'inspection par thermographie active, le panneau de graphite époxy (non visible sur la photo) est situé en face de la caméra infrarouge visible au centre. Les lampes (6x100W) sont allumées pendant 2,5 s pour stimuler l'échantillon. (b) Une délamination de 5mm de diamètre, localisée 2mm sous la survace apparaît quelque 20 s après le début du chauffage. (c) Après un traitement d'image adéquat, le défaut apparaît plus clairement.

pour les détecteurs thermiques. Puisqu'un minimum d'énergie est nécessaire pour émettre des électrons ou des porteurs de charge, la réponse du détecteur dépend de la longueur d'onde des photons et des propriétés du matériau dont est fabriqué le détecteur, par exemple: InSb, antimoniure d'indium, 3 à 5,5μm; HgCdTe, tellure de cadmium-mercure, 8 à 12 μm. Un refroidissement approprié (azote liquide, effet Peltier, cycle de Stirling) permet d'obtenir une bonne plage dynamique (≈42 dB) et un niveau de bruit faible (NETD = 0.1°C, *Noise équivalent Température Différence)*.

Trois types de caméras à détecteur photonique sont disponibles.

Type 1 Caméra mono-détectur, formation mécanique de l'image par prismes ou miroirs rotatifs (coût ≈ 50k$).

Type 2 Caméra à détecteur Sprite (Signal Procesing in the Element), une barrette de détecteurs est employée pour accroître de rapport signal sur bruit, formation mécanique de l'image (coût ≈ 6k$).

Type 3 Caméra à matrice de détecteurs (photodiodes au silicium de platine (PtSi, 1 à 5,5 μm), formation électronique de l'image (coût ≈ 100k$)

Les caméras de type 3 offrent une résolution spatiale accrue étant donnée le nombre élevé d'éléments sensibles de la matrice, typiquement 512 x 512 éléments aussi appelés pixels. Cependant, l'étalonnage précis en température est ardu à cause de la réponse non uniforme des pixels. Cet handicap s'applique également, dans une certaine mesure, aux caméras de type 2 qui peuvent présenter en plus des effets de traînage lors du suivi de cibles mobiles. Les nouvelles générations de caméra à mono-détecteur (type 1) offrent une robustesse accrue, une compatibilité avec les signaux vidéo standard (RS-170) et une facilité d'étalonnage (détecteur unique), au prix toutefois d'une résolution spatiale un peu moindre. Pour les applications de vision infrarouge, où l'aspect quantitatif de la mesure est primordial, ce dernier type d'équipement est à privilégier tant que les caméras de type 3 n'auront pas atteint une réponse de pixel à pixel suffisamment uniforme et surtout un coût plus abordable, ce qui devrait survenir dans les prochaines années, de 2 à 3 ans estime-t-on, avec le perfectionnement des techniques de fabrication des détecteurs.

Les principales bandes spectrales employées sont les bandes 3 à 5 μm et 8 à 12 μm. Ces bandes sont choisies car elles correspondent à des fenêtres atmosphériques où les radiations sont transmises sans trop d'atténuation. Le choix d'une bande est spécifique et l'application envisagée. D'une façon générale, sur les courtes distances (inférieures à 1 km) et aux basses températures (moins de 100 °C), la bande 8-12 μm est favorisée puisque l'émission thermique de la matière, telle que stipulée par la loi de Planck, est alors supérieure. Aux plus hautes températures, l'inverse se produit et la bande 3-5 μm est privilégiée.

Comme autres équipements nécessaires, il faudra un magnétoscope vidéo pour la capture, l'analyse en différé et l'archivage des résultats. Une unité de traitement (ordinateur de type PC par exemple) permettre de réaliser des traitements d'images spécifiques. Des logiciels sont d'ailleurs souvent disponibles auprès des manufacturiers de caméras ou peuvent être développés séparément. Dans le cas de l'approche active, des unités de chauffage (lampes, éléments radiatifs) ou de refroidissement (ligne de jets d'air) seront aussi nécessaires pour la stimulation thermique des pièces à inspecter.

Le pour et le contre de l'ÉND par thermographie

En évaluation non-destructive des matériaux (ÉND), aucune technique d'inspection n'apporte de solution à tous les problèmes. Il s'agit souvent d'employer une combinaison de techniques. Ainsi, on pourra d'abord effectuer un tri rapide des pièces, sur la base acceptation-rejet à l'aide de la thermographie infrarouge, puis reprendre les pièces jugées fautives pour une inspection plus fine, par ultrasons, en vue du re-travail de celles-ci.

Chaque technique a ses forces et ses faiblesses et dans le cas de la thermographie on s'entend généralement sur les avantages suivants:

- rapidité d'inspection;
- absence de contact (aucun couplant n'est nécessaire, ce qui n'est pas le cas des ultrasons, par exemple);
- sécurité puisqu'aucune radiation dangereuse n'est impliquée (ce qui n'est pas le cas de la radiographie aux rayons X, par exemple);
- facilité relative d'interprétation des résultats (images);
- grande versatilité d'application;
- outil parfois unique pour l'obtention d'informations au sujet de la structure interne d'une composante (c'est le cas par exemple des revêtements de céramique pouvant difficilement être testés par d'autres méthodes d'ÉND).

Il faut cependant mentionner un certain nombre de problèmes relatifs à ces techniques de vision infrarouge tels:

- la difficulté d'obtenir un dépôt d'énergie élevé, uniforme et bref sur une grande surface (pour l'approche active);
- l'effet des pertes convectives et radiatives qui provoquent des contrastes perturbateurs;
- le coût élevé de l'instrumentation (cet aspect devrait s'atténuer dans le futur avec la réduction des coûts liés à la fabrication des caméras à matrice de photodétecteurs);
- les problèmes d'émissivité.

L'émissivité est la propriété d'une surface d'émettre de l'énergie. Une surface ayant une faible émissivité aura tendance à se comporter comme un miroir, il sera alors difficile de mesurer sa température par une méthode radiative puisque les radiations émises par les corps avoisinants perturbent les lectures en se réfléchissant sur la surface. Diverses techiques peuvent solutionner de problèmes: application d'une peinture de haute émissivité, emploi d'une cavité réfléchissante (pour accroître artificiellement l'émissivité par un effet de réflexions multiples), observation simultanée dans plusieurs bandes spectrales (pyrométrie à 2 longueurs d'onde), transfert des empreintes thermiques par une pelure ou un rouleau de haute émissivité. Une bonne connaissance des avantages et limitations des techniques d'ÉND permet de mieux envisager des solutions au problème d'inspection considéré et de juger de la pertinence de l'usage d'une méthode d'investigation particulière.

Conclusion

La vision infrarouge est une technique encore jeune qui offre de multiples possibilités pour l'évaluation non destructive des matériaux et structures. Lorsque les défauts (anomalies quelconque, mauvais fonctionnement) provoquent un échauffement localisé, une technique passive qui consiste à pointer directement une caméra infrarouge sur les endroits suspects permet de rapidement identifier les problèmes par simple visualisaiton des zones anormalement chaudes dans les images.

Pour évaluer les défauts qui ne provoquent pas de différences anormales de température par eux-mêmes, cas des fissures, délaminations, décollement, inclusions de matière étrangère, porosité, une méthode active par laquelle les composantes sont stimulées par un bref apport thermique est nécessaire. Associée à des traitements d'images spécifiquement adaptés, l'étude quantitative devient possible, on peut ainsi évaluer la profondeur, le contour, les dimensions et la résistance thermique des défauts.

Avec la mise au point prévue d'ici quelques années de caméras infrarouges à matrice de photodétecteurs plus sensibles dont le coût devrait être comparable à celui des caméras vidéos CCD conventionnelles (environ 2k$) et l'élaboration de logiciels spécialement adaptés pour l'accroissement des contrastes thermiques, on s'attend à une utilisation beaucoup plus généralisée de la vision infrarouge dans le milieu industriel.

Fire: The unchecked threat

In a recent article "Fire: The Unchecked Threat", Mr. Campos assumes that most electrical fires in residences are due to arcing faults which would have been prevented had a GFI (ground fault interrupter) been used. Out of about 800 fires that I have investigated, there are only two cases in which a GFI, possibly, would have prevented the fire.

Arcing faults very seldom happen at residential voltages. To convince himself, Mr. Campos should try to start such an arc in a typical residential circuit. It is extremely difficult to achieve. However, under fire conditions, the insulation is pyrolyzed and changed to carbon particules that act as a kind of semiconducting medium. Under such conditions, arcing can be quite stable and last many seconds or even minutes without operating the protection device. In the process, many centimeters of the conductor could be melted. However, this is a consequence of the fire and not the cause. It is regretable that the fire investigation community had, for years, interpreted the beadings left by the arc as evidence of the cause while, in fact, it was just a consequence. This writer has written numerous articles on the subject and has conducted tests on fires for the last 15 years.

One should be very careful when using the Fire Commissioner's report. Fires are often investigated by retired fire fighters who have very limited knowledge of electricity, let alone of the behaviour of fires. Furthermore, most statistics do not reflect the exact cause. Causes are often classified under vague terms such as electrical and mechanical failures under the same heading.

Figure 1 of the article shows three large buildings fully engulfed in fire: The title of the figure is "Typical examples of electrically - induces fires." One wonders if the author suggests that any large-scale fire must be due to electricity. That would be in line with much of the statistics on fires that tend to show that the larger the fire, the more likely the assumed cause to be due to electricity. The statistics show that electrical fires do more damages on a per-fire basis than arson fires. One would have expected the reverse situation since an arsonist would use the proper material at the right place and time to do the outmost destruction. An electrical fire would start as a small fire and would take some time before it becomes fully involved.

At 120V and 5A arcing current, for 3.5 second, Mr. Campos found an energy of 16450 Joules. The result should have been smaller than 120 x 5 x 3.5 = 2100 Joules, since both the voltage and current are non-sinusoidal under arcing conditions.

Electrical fires do exist. The percentage of fires due to electricity is probably about 2 or 3%. Often electricity is pointed without any evidence except for the mere presence of electrical wiring. There are numerous examples of fires for which electricity was pointed as the cause and found later to be due to an entirely different cause such as careless people or even arson.

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The Author Responds:

During the fulfillment of the functions of my present position, I had the opportunity to witness several times the devastating effects of electrical fires. Whether the fire was initiated by an electrical fault or fed by electrical faults appearing as consequence of the fire, the destructive power of the electrical-originated fires was awesome.

I agree with the reader that arcing faults are rare at residential voltages and that under normal conditions they are not stable. That much was also stated in my article. However, this represents small consolation for the people touched by electrical fires and unfortunately they are a lot more than anyone may wish.

The Fire Commissioner's report is an official document which presents a statistical compilation of the causes and consequences of all the fires that have occurred. This is done by competent and dedicated people, who rely on a lifetime of experience and have good training to do it. Certainly, the report has all the shortcomings of any statistical analysis. But, due to the size and diversity of the sample on which the report is based, I would tend to rely a whole lot more on its conclusions than on the conclusions of any local organization or single indivudual. Specific conditions of the local population in any area (such as education, social development, economic condition, average age of buildings, etc.), may have a fundamental impact in the causes of fires in such areas and contribute to the establishment of conclusions that are not valid in general. In any case, I wonder on what statistical basis the reader established that the percentage of fires due to electricity is probably around 2 or 3 percent.

Figure 1 of the article was not intended to suggest that electrical fires are usually of large scale. They were inserted in the article just for illustrative purpose. As matter of fact, the three photos are all of the same fire and the legend should have been "Typical example" instead of "Typical examples". Fortunately, many electrical fires do not reach such proportions.

If the reader wished to verify the calculation for the energy released during a typical fault, as the one included in the article, I suggest that he take into consideration the thermal effects of the harmonics that are present in any fault. Depending on the restrike voltage chosen, the number may be higher or lower than the 16450 Joules proposed in the article. It should however be in its vicinity.

Finally, I must say that the urge to write "Fire: The Unchecked Threat" arose from my sincere belief that such fires are a tragedy that can and should be prevented. My objective was to call once more attention to this situation and to suggest a possible way to deal with it. I was not even original in my effort, since I offered solutions already adopted elsewhere and I focused on a problem that has been deeply covered by technical publications, such as "IEEE Transactions on Industry Applications" and "Fire Journal." But, I tried to a make a difference...

Jorge Campos
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