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The author visited Yugoslavia's Universities of Belgrade and Sarajevo, the Institute for Control and Computer Sciences of the Energoinvest company, and two research institutes – Stefan Institute and Rudger Boskovic Institute. He reports on the control theory, fluid mechanics, and other research being done there. (eda)

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RESEARCH IN FLUID MECHANICS, CONTROL THEORY AND SUCH IN YUGOSLAVIA

Introduction

During my visit to Yugoslavia I visited two mechanical engineering departments (at the Universities of Belgrade and Sarajevo), the Institute for Control and Computer Sciences of a large research and development company (Energoinvest), and two research institutes (Stefan Institute and Ruder Boskovic Institute). In this way I was able to see how industry interacted with the universities and how a couple of important research institutes fitted into the research environment. My visit covered Serbia, Bosnia-Hercegovina, Slovenia, and Croatia. The distinction between different provinces is important since, due to language and cultural differences, it is rare for a scientist or engineer to move from one province to another.

Money for research appears to be allotted at the province level. There is, however, a joint US and Yugoslavian board that funds research throughout the country. For this program the US donates at present $2 million, which is matched by Yugoslavia. The resulting $4 million is used to fund research projects that can include travel to the US. Present tight currency restrictions can have an adverse effect on research since it makes the procurement of new western equipment difficult. At the same time, as will be seen, the currency restrictions can create sheltered niches of technology within Yugoslavia both for research projects and development of technical equipment.

At all the institutions that I visited, there was heavy emphasis on education in or research visits to America. Many of the people I talked to referred to the fact that Yugoslavia had a window to the West and a window to the East. The window to the West seems to be more open than the one to the East, since on questioning, I found that few scientists visit Russia for extended periods. One of my hosts had a simple reason for this when he indicated that one went simply to the source of research – i.e., America. I begin my review by a discussion of the Mechanical Engineering Department at the University of Belgrade, followed by a discussion of Energoinvest's Institute for Control and Computer Science and the Mechanical Engineering Department at the University of Sarajevo. The discussion concludes with a review of the two research institutes in Slovenia and Croatia.

The University of Belgrade's Mechanical Engineering Department

With a student enrollment of over 6000, the Mechanical Engineering Department of the University of Belgrade is the largest such department in Yugoslavia. Among the wide variety of the department's activities are studies in railway engineering, ship engineering, process engineering, mechanics, military engineering, combustion engineering, production engineering, and aerospace. I was principally interested in the aerospace group, which is unique in Yugoslavia. This group, which is directed by Professor T. Daganovic, has about 30 professors and 50 undergraduate and 20 postgraduate students. The classical disciplines of aerodynamics, structures, and propulsion are taught, and a new group in avionics which is concerned with aircraft armament, flight testing, and reliability is just starting. Research is closely related to the teaching disciplines, and the aerospace group has a close relationship with the Aeronautical Institute (VTI), which has extensive wind tunnel test facilities about 40 kilometers from the university. The aerospace group has its own supersonic tunnel (test section of 0.25x0.25 meters) and subsonic tunnel (2.8x2.2 meters). Daganovic indicated that the group also uses VTI's hypersonic (M = 7), trisonic (1.5x1.5 meters), and large low-speed wind tunnel (4.4x3.2 meters). The hypersonic and trisonic tunnels (based on a Canadian design) were put into operation in 1983.

The department's research work is commercially and militarily oriented, and thus, there are few open literature publications. The group's previous work has concerned environmental aerodynamics for a harbor in Pakistan, the aerodynamics for a bridge, and some automobile and motorcycle aerodynamic measurements. The group's principal research activity at present is connected with the design and development of a Yugoslav multipurpose civilian and military helicopter, the VNH-90 (a project initiated by the aerospace group). In the VNH-90 design and development the group has responsibility for the rotor aerodynamics, stability and control, and development of the composite material for the rotor. I saw one of the composite rotors undergoing test. The project appeared to me to be a very severe test of the capabilities of the aerospace group, but I understand that some

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cooperative efforts in this work are planned with American helicopter companies.

Energoinvest's Institute for Control and Computer Science

The Institute for Control and Computer Science, located in Sarajevo, Bosnia-Hercegovina, is part of a $2 billion company, Energoinvest, which is active, as its name implies, in the energy field. The company, which is the largest exporting company in Yugoslavia, has over 55,000 employees and five divisions. Its R&D activities are directed at electric power systems and plants, thermal power and process plants, and information and control systems. Other activities include the production and processing of nonferrous metal, and the processing and production of oil products. There is strong emphasis on R&D, and Dr. M. Aganagic, Energoinvest's Vice President for R&D (and my host for the visit), indicated that the company spends twice as much on R&D as the Croatian republic does. About 1000 Energoinvest people are involved with R&D. The company has five scientific research centers, all in Sarajevo, which were cofounded with the Academy of Science and Fine Arts of Bosnia-Hercegovina. The centers are the Institute of Electric Power (IRCE), the Institute for Thermal Technique and Nuclear Technique (ITEN), the Institute for Control and Computer Science (IRCA), the Institute for Welding (IZE), and the Center for Research and Development of Materials (CIRM). I was principally interested in IRCA, but other interesting work is being done at the other centers – for example, superconductivity is being investigated at CIRM. In my visit to the Mechanical Engineering Department of the University of Sarejevo, discussed below, I became acquainted with the the ITEN center. The centers are closely related to the university and professors lead the work in the scientific centers.

With respect to the close interaction of Energoinvest and the university it is interesting that Aganavic indicated that the company essentially developed the university's Mechanical Engineering Department at Sarajevo and greatly aided the development of its Electrical Engineering Department. This action of the company was motivated by the perception that in order to be world-competitive the technology base upon which the company functioned needed to be raised. Thus, technological innovation in a certain sense proceeded from industry to academia. In addition to its scientific centers, Energoinvest has four R&D centers and two information and computer support centers.

The Institute for Control and Computer Science has three main areas of investigation: design and development of complete automatic systems for power plants and water supply systems, robotic research, and computer vision. The automatic systems activity consists of R&D for systems and devices for measurement, control, and regulation of technological processes – and this includes the development of the central computer system. The company has recently won a competitive bid for a large automated energy system in a Southeast Asia country. The institute's equipment looked very advanced, including the incorporation of a distributed processor (Salihbegovic, 1987), but there did not appear to be the obviously desirable extensive computer simulation facilities. Development of such equipment requires either the purchase of microprocessor devices or the development of a local microprocessor technology base. Due to currency restrictions, and also to the desire to develop local computer capability, both the institute and the parent Energoinvest have put a large investment in people and facility in the development of a microprocessor laboratory whose head, N. Mekni, was educated at Amhurst College, Massachussetts, and the University of California at Los Angeles. The laboratory uses purchased chips to produce hardware devices with relevant software. The devices include data acquisition control equipment, a local area network for powerplants, and process controllers.

One of the major projects for the domestic market is the development of a supermini 32-bit computer (like an Apollo or Sun) and a PC-like computer based on the Intel 386 chip. Behind Yugoslavia's currency restriction wall is a captive market for such equipment. A new building for fabrication of the computers is presently under construction. One of the advantages of such research or development is that it supplies advanced microprocessor equipment to the turnkey automatic systems sold by the company.

I was shown some of the present experimental investigation going on at the institute. The first experiment involves use of a fluidic oscillator whose frequency is proportional to the flow rate of the material being measured – in this case, steam. Steam is a dirty substance which causes difficulties in the measurements, and these experimenters aim to achieve an accuracy of ± 2 percent with their device. (By contrast, The Harry Diamond Laboratory in the US has a similar device, but with an accuracy of only 10 percent.) Not surprisingly, there is a large market for a cheap, reliable steam flow sensor in Yugoslavia – present large regenerative heating plants have no way of charging the individual customer so there is no incentive to conserve energy.

A second of the institute's efforts, one which is actually well established, is the development of force transducers based on strain gauges. These force transducers are presently a domestic product. Further extension of these devices will involve a variable authority control for aircraft. The third experimental setup that I saw was concerned with machine vision. This setup uses an American digital processing system and an American robot to investigate the means for recognition of complex two-dimensional objects. Consideration is now turning to grey-scale objects.

Some theoretical work has been conducted on the use of sliding mode control in electrical power converters and induction motors. Future application of this nonlinear control is felt to be promising in the motion control of a robot, and simulation results of this type of control are now available, A. Sabanovic of the institute is presently working in Japan on robot control. Simulation results of this type of control are now available.

The University of Sarajevo's Mechanical Engineering Department

The Mechanical Engineering Department at the University of Sarajevo has about 80 professors and about 620 students involved in a 4-year program. About 200 to 250 students graduate each year, and since there is a strong demand for mechanical engineers in Yugoslavia, they are quickly employed. About 70 percent of the support for the department comes from government funds, the other 30 percent from research contracts. I talked with Professor Z. Mirkovic, who is Dean of the thermosciences part of the faculty. The department has a strong applied orientation with five divisions studying mechanical production, process technology, mechanical technology of wood, manufacturing engineering, and energy process techniques.

Many research projects are closely connected with the region and with the city of Sarajevo. These include air quality protection, energy use and combustion installation, and the development of new industrial products. Particular projects are studies of the effect of stack height on pollution, thermal efficiency of solar collectors, road tunnel ventilation systems, and mathematical modeling of transport processes in the environment. Dr. K. Hanjalic, who obtained his Ph.D. under B. E. Launder at the Imperial College, has directed the research involving environmental flow calculation. I had met Hanjalic before, when he lectured on turbulence models with Launder in America. Although Hanjalic has just finished a number of years as mayor of Sarajevo, he has kept technically current. His recent technical work on heat transfer and natural convection – involving a contract from the US Environmental Protection Agency – has resulted in a paper on free convection flows in arbitrarily shaped enclosures. The department's other work in computational fluid mechanics has included the introduction of higher order modeling in the Grosman codes from the UK's Imperial College and in turbulence modeling.

A new building which will have a laboratory devoted to coal combustion is being considered. Hanjalic with two colleagues from Energoinvest's ITEN has reported on the feasibility analysis of direct gasification of pulverized coal in a steam reactor. There is presently a joint German and Yugoslav program on reducing pollution and developing more efficient coaling technologies. Another article from this joint program is concerned with the application of a detonation-wave technique for on-load cleaning of gas-side surfaces of steam boilers. In keeping with the practical orientation of the research work is the development of compressor simulation codes by Dr. N. Stosic which are used in the design and development of compressors in Yugoslavia. In particular, modeling has been done for screw compressors, which are a type of medium-range compressor made by a local factory. The codes have been developed locally since foreign licences are extremely expensive – another example of the foreign currency restriction wall.

Jozef Stefan Institute

The Jozef Stefan Institute, located in Ljubljana, Slovenia, was originally founded as a separate research institute oriented towards physics and nuclear research. Research areas have since been widened, and ties with the Edvard Kardelj University are being strengthened in that the institute is becoming formally a part of the university. There is also some relationship with the other Slovenian university, at Maribor. Present areas of investigation include: theoretical physics, solid-state physics, nuclear engineering, chemistry, ceramics, biochemistry, and electronics. (My particular interest in this visit concerned the electronics area, in particular, control theory, robotics, and computer science or informatics.)

There are about 500 professional people working in the institute, of whom about 250 have doctorates or master's degrees. About one-fourth of the people are working in what could be termed basic scientific research, and the other three-quarters are in applied research. There is heavy emphasis on applied research which is important or what is perceived as furthering the national growth and development. Around a hundred of the technical staff also work at the university. In a recent year the staff produced 900 publications of which 300 were in the open literature. Support for the institute is 50 percent from the government (Slovenia) and 50 percent from direct contracts. Computer facilities appear adequate – three Vax 750's and several small computers.

My host for the visit was Dr. T. Kalin, director of the institute. Kalin spent a year (1966-67) on a Fulbright at Rensselaer Polytechnic Institute in Troy, New York. About 10 of the staff, which Kalin considers a normal number, are now working in the US. There is presently an American professor working at Stefan in the solid-state physics group. Kalin teaches two courses at the university in computer performance evaluation. So the integration of the institute and the university starts at the highest level.

Electronics. Research in the Electronics Division is concerned with the development of modern microcomputer control systems, industrial robot systems, systems for energy conservation, computer hardware and software, and information systems. One of the recent control problems solved in the computer automation and control group was concerned with automation of a paper

mill involving batch processing. Although there is a commercially available Finnish paper control manufacturing system which has been available for over 10 years, it was decided due to currency restrictions and the desire to improve the technological base to develop a uniquely Yugoslavian control system. Currency restrictions thus provide, as indicated before, a protected technological specialty within the country. It remains to be seen if this approach can lead to world-competitive technology.

Marko Sega et al. (1986) reported on the application of computer aided design to the semibatch column control connected with the paper mill. The total system design, which took 4 years of effort, involved seven batch digestors and was said to be very successful, with savings in a year equal to $3 million, which happened to be also the total cost of the project. The project was concerned with simulation of the process; further work is in progress on increasing the knowledge base and on increasing, the applications of adaptive control.

In the control system design, just discussed, use was made of an interactive computer aided design package called ANA which has been under development for 5 years at the Stefan Institute. The code is intended for use in industry and by academia in Yugoslavia. The code is fairly extensive, incorporating many of the features available in similar commercial codes in the West. Thus the code has frequency domain, state space analysis, identification, block synthesis, and simulation of control systems. The code seemed well designed but as with many of these user friendly codes it is difficult to make a valid judgement unless one has used it. ANA is the principal design tool in control theory at the Stefan Institute. Reports on the code were given contained in several recent IFAC meetings and in the proceedings of a recent workshop on process automation which developed from a cooperative West German-Yugoslav program in science and development

The cooperative West German-Yugoslav program is funded by Kernforschungsanlage Julich and consists of a joint research program in process automation with the control institute of the Technical University of Darmstadt. The proceeding of a workshop on process automation held in Ljubljana on 21-25 April 1986 and published by Julich is of interest since it summarizes much of the recent activity in control theory at Stefan and Edvard Kardelj University. In addition to the ANA program and the paper mill process control previously discussed, the proceedings contain articles on feed-forward identification and its application to robotics, design of a compensator for static nonlinearities, and the use of the Inverse Nyquist Array Method in design with multivariable control. The robotics work is essentially an adaptive feed-forward compensator for trajectory control. This work was accomplished by D. Matko while at Darmstadt.

The Stefan Institute's Robotics Laboratory, directed by Dr. J. Lenarcic, was founded in 1985, although the institute's work in robotics goes back to 1979. In September 1987 a first report on the activities of this laboratory was issued. The research projects of the laboratory deal with mathematical modeling of robot kinematics and dynamics, robot control, robot programing, robot simulation, computer aided design of manipulators, and three-dimensional measurements of robot movements. Research activity is supported by the Slovenian Research Community, but development projects are funded by direct contracts with industry. The Robotics Laboratory is the coordinator of the Slovene Robotics Project, which involves over 30 industrial companies and the two Slovene universities. In the area of industrial applications a spray-painting and an assembling robot have been developed. These robots were demonstrated for me. A new spot-welding robot and a new arc-welding robot are currently under development. The laboratory is well equipped with Tektronic display terminals, microcomputers, four industrial robots, and commercial vision and displacement measuring devices. Advanced mathematical modeling and simulation of robots and robot trajectories is done on a Vax 750. A recent publication in this area by Lenarcic et al. (1987) is on the design of robot manipulators based on kinematic analysis. The laboratory research and development program appears to be well coordinated and well financed.

Ruder Boskovic Institute

The Ruder Boskovic Institute, located in Zagreb, Croatia, and founded in 1950 by the Yugoslav Academy of Sciences and Art, is affiliated with the University of Zagreb and with the Dr. Vladimir Bakaric University in Rijeka. To a large extent the institute serves as a postgraduate school for the University of Zagreb. Much as the Stefan Institute in Slovenia, the Ruder Boskovic Institute was founded originally to do research in nuclear sciences, but has since expanded its areas of interest. The institute engages in pure and applied research in physical, chemical, biochemical, biomedical, and marine and environmental sciences. In the more applied area there are units in nuclear, solar, optical, and chemical technology and production. The total staff numbers about 850, of whom 220 are Ph.D.'s and 120 M.Sc.'s. Normally about 90 students are doing a master's degree, and last year 12 doctoral degrees were awarded. Funding is about two-thirds from the government, and one-third from industrial sources.

I was interested in the Material Science and Electronics Department as well as the Laser Department. Although I had an opportunity to talk to the people engaged in control theory, it developed that they were all working on missile projects for the military and could tell me nothing of what they have done. Our conversation was monitored and there were no publications available in the controls area. In the Laser Department, work is of a fairly practical nature. About 50 people make complete laser systems, including laser targeting devices for the army.

The US Army Material Command in Frankfurt, West Germany, supports work on imaging through water and propagation of laser light through water. There is also considerable activity in the development of optical thin films for goggles as protection against laser light. Industrial applications include the development of laser welding and laser heat-treating equipment. Emphasis is on the development of the complete device for its industrial application, not just the laser. Presently there is a person working in America in the laser area.

My visit to the laboratory which was conducted by my host, Dr. S. Kveder, was somewhat curious as we walked about the campus looking at the outside of buildings. Whether Kveder did not understand the purpose of my visit or I was simply excluded for some political reason, I do not know, although I suspect it was mere misunderstanding. I did get to see one laboratory which contained a large Van der Graff generator recently obtained from Rice University, Houston, Texas.

From the institute's yearly report (in Croatian) it is possible to glean some further information. The institute generates a large number of publications in the open literature (about 450), all published in English, with additional articles in Croatian. Most of the listed publications are in physics, chemistry, biochemistry, and mathematics. I would characterize the publications as typical of a good graduate school with a heavy emphasis on fundamental research. There is a group of workers from the institute, about 30 in number, who are presently engaged in research in the US. Perhaps 20 of these are taking their doctorates there. There is also extensive interaction with West Germany and Italy. Boskovic Institute serves as a research center for Croatia, much as the Stefan Institute serves as a research center for Slovenia. I believe from what I saw that the Boskovic Institute puts less emphasis on applied research than the Stefan Institute.

Conclusions

Research in Yugoslavia is primarily applied research, industrially oriented. Major new fundamental research is not evident, but the applied work is very well done by competent researchers, many of whom did their advanced academic work in the US. There appears to be a healthy industrial and academic interaction which I have found missing in other developing countries. In fact the Energoinvest company seems to have taken the initiative in development of what it perceived to be a necessary scientific base in the local university. The research institutes, particularly the Jozef Stefan Institute, have also a strong applied slant and are well integrated into the technology of the country. The different republics or provinces of Yugoslavia provide a competitive element in the research environment much as the different states in the US do. This element and the willingness of the Yugoslavians to emulate and follow US research methods has, I believe, reflected to their benefit.

One curious aspect of Yugoslav research is the large effect of their currency restrictions in development of protected technology niches in the country. This can be good for technology development if world-competitive work is the eventual outcome. On the other hand, such a protective wall, if they are not careful, could lead to mediocrity.

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