2.3 ABOUT CNC MACHINES

The role of mechanical engineering in economy of every state with advanced industry is irreplaceable. The general development of all other economical branches of one or another country depends on the development of mechanical engineering. Every object which can be found around us carries a trace of a production machine (i. e. of a machine tool or of a forming machine) – this can be a car, a phone, a TV set or other things elevated by society to consumer things. These can be also manufacturing facilities important for human being (a turbine – production of electric power, food processing machines – production of food, etc.).

Definition of the term "CNC machine tool"

The numerical control (often designated by the English abbreviation CNC – Computer Numerical Control) is understood in the larger word sense as operation of a digital computer specified to control the tool motion or the workpiece motion by defined speed along the determined trajectory in the space or in the plane. When the numerical control of machine tools is considered, this is the control of the particular machining process and auxiliary functions based on numerical data and commands.

All information types necessary to machine a part are recorded as a sequence of numerical characters. The information necessary to machine the particular workpiece can be:

- information specifying the workpiece dimensions;
- information characterizing various functions (feed, speed, ...);
- auxiliary information (switching-on coolant, ...).

So, the CNC machine tool is the machine tool which is numerically controlled and its design is adapted so that this machine tool can work in the automatic cycle and it has the automatic tool exchange or the automatic workpiece exchange available. The numerically controlled machine tools of older generations used NC control systems, while CNC control systems are exclusively used today.

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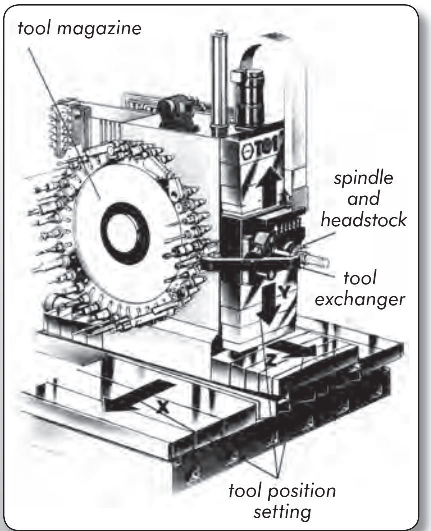

Fig. 2.3.1: Main parts of the numerically controlled machine tool [INA]

In the past time as well as today the numerical control (NC – Numerical Control) is understood as the automatic control of the machining process by means of the device which uses the entered numerical data for its operation.

The NC control system used in the past time often used single purpose automats to perform the numerical control of a machine tool. At the single purpose automats, software and operating circuits are made by the fixed connection and e. g. a punch tape was used as the data carrier.

In comparison with these systems, the current CNC control system uses a computer to realize the numerical control. At the CNC control systems, the information processing part consists of the built in computer which has all important system functions stored in the memory as software blocks, unlike the NC control system which has these functions and operating circuits firmly connected. Another CNC control advantage compared to the NC control consists in the possibility to adapt this control system by means of software blocks to the machines having various numbers of controlled axes, functions, etc.

As is follows from the above mentioned facts, it is necessary to distinguish the terms "numerical control" and "CNC (NC) control system".

The numerically controlled machine tool has usually six main working assembly groups (Fig. 2.3.1):

1. tool position setting (workpiece position setting);
2. the spindle with the headstock;
3. the tool magazine and the tool exchanger;
4. the workpiece magazine (exchanger);
5. supplies of media;
6. protective guards.

History of CNC machine tools

Parsons and NC invention [www-1]

The NC birth is commonly ascribed to John T. Parsons, a mechanician and businessman of Parsons Corp. company, which was owned by his father and which dealt with machining.

In 1942 Bill Stout, previous chief of manufacture in Ford Trimotor company told him that "another great thing" will be helicopters. Parsons contacted Sikorsky Aircraft company to ask about possible work and soon he received the contract for manufacture of wooden girders in rotor blades. After a short time, when he had started manufacture in an old furniture factory and this manufacture had been accelerated, one of the blades ruptured and it imprinted in the wing spar. When the fact came out that some problems can be found along the whole length of point welding by means of which the metal collar of the wooden girder was attached to the metal wing spar, Parsons designed a new method how to attach girders to the wing spar using glue, which had never been used in design of aircrafts before.

However, this event encouraged Parsons to start thinking about possibilities to use pressed metal girders instead of wooden ones, the manufacture of which would be much easier and which would be stronger too. The girders for rotors were manufactured according to the design given by Sikorsky company which was sent as a set of seventeen points which defined the contour. Parsons had then "to fill" points using a French curve to create the contour which could be used as a pattern for manufacture of jigs for the wooden version. But how to manufacture a tool able to cut metal and having this shape, it was a much more difficult problem. Parsons visited Wright Field company to meet Frank Stulen there. Frank Stulen was the chief of the branch of rotary rings in the propeller laboratory. Stulen came to a conclusion that Parsons really did not know what he was speaking about and when Parsons recognized this, he offered work to him at once. On 1st April 1946 Stulen started to work for Parsons and he employed three new technicians to join him.

Stulen's brother who was working at Curtis Wright Propeller company mentioned that they were using calculators with punched cards to perform calculations. Stulen decided to take this idea to perform the stress analysis for rotors, which were the first detailed automatized calculations for helicopter rotors. When Parsons saw what Stulen was doing using the device with punched cards, he asked him whether this could be used to create the contour having 200 points instead of seventeen points which were given to then and to move each point by the radius of the cutting tool at the milling machine. If cutting were performed in each of these points, it would create a relatively exact cut out of the stringer even of hard steel and it would be possible to fill this cut out off easily to the smooth shape. The resulting tool would be useful as a pattern to stamp metal girders. It was no problem for Stulen and he used points to create large tables with numbers which were given to the workshop. One of the operators was reading numbers of these cards for two other operators and each of these operators was working on one of the X axis and the Z axis. These operators moved the cutting head to the particular point and performed the cut. This process was called the "method according to numbers".

At that time Parsons started to deal with the idea about a fully automatized tool. If the sufficient quantity of points were available, manual work would not be necessary at all. However, at manual control the time saved improving the workpiece to comply better with the final shape is compensated by the time necessary to move control elements.

If the machine inputs were connected directly to the card reader, time delay and all associated manual errors would be eliminated and the number of points could be incredibly increased. Such a machine could stamp perfectly exact patterns based on the command and repeatedly. However, at that time Parsons had no financial means available to develop this idea further. During a visit at Wright Field company, one of Parsons's businessmen learnt about the problems which the newly created US air force had with new designs of jet aeroplanes. Based on this, Parsons offered the idea with the automatized milling cutter to Lockheed company, but this ide was not interested for them. Lockheed company already decided to use five axis pattern copying machines to manufacture girders and these machines should cut from the metal pattern.

This company even ordered an expensive cutting machine. Parsons remarked to this: "Now, imagine this situation for a while. Lockheed concluded the contract to design a machine which will manufacture wings. This machine had five cutting tool motion axes and each of these axes was controlled by the copying device using the pattern. Nobody used my method how to make patterns. So, imagine what chance they will have to manufacture the exact shape of the aeroplane component with inaccurate patterns."

Parsons's concern came soon true and in 1949 the US air force determined financial means for Parsons so that he could build his machines by himself. Work with Snyder Machine & Tool Corp proved soon that the system to drive the control elements directly from the motor was not able to have the accuracy which was necessary to adjust the machine for the perfectly smooth cut. Because the mechanical control elements did not respond in the linear way, they could not be simply driven by certain quantity of power, because the differing forces which would mean the same quantity of power would not always cause the same motion measure in control elements. It did not depend on the number of points included in the contour, the contour would be still rough.

Input of MIT [www-1]

Is was not the problem which could not be solved, but this required a certain kind of the feedback system, like a selsyn is, to measure directly to what measure the control elements really rotated. In spring 1949 Parsons addressed the Laboratory of Servomechanisms, MIT, the world leader in mechanical calculations and feedback systems with the complicated task to compose such a system. During the war the laboratory composed many complicated motorically driven devices, as motorized systems of the revolving weapon cartridge for B-29 and the automatic copying system for the radar SCR-584. The laboratory satisfied the requirement to build the prototype of Parsons's automatized machine controlled by the "method according to numbers". The MIT team was led by William Pease, who had James McDonough as his assistant. The both people came very quickly to the conclusion that Parsons's design could be considerably improved, if the machine did not make only the cuts in points A and B, but it would move continuously among the particular points instead. Then, this would not only create the perfectly smooth cut, but it could be performed with a smaller number of points – the milling cutter could cut contours instead of having a great quantity of cutting points defined to "simulate" the contour. The tripartite agreement was concluded among Parsons, MIT and the air force and the project was taking place officially from July 1949 to June 1950. The contract required to design two "automatic milling machines with cards", of the prototype and of the manufacturing system. Both should be submitted to Parsons to be connected to one of his milling cutters for the purpose to develop a deliverable system to cut stringers.

Instead, in 1950 MIT bought the superfluous "Hydro-Tel" milling cutter from Cincinnati Milling Machine Company which was made by this company and MIT concluded a new contract directly with the US air force which excluded Parsons from another development. Later, Parsons commented it by the words: "I have never dreamt even in my dreams about the possibility that somebody having such a good name like MIT could intentionally proceed in this way and take my project".

Although the development was submitted to MIT, on 5th May 1952 Parsons made the patent application for the "motorically controlled device for machine tool position setting", which encouraged MIT to make

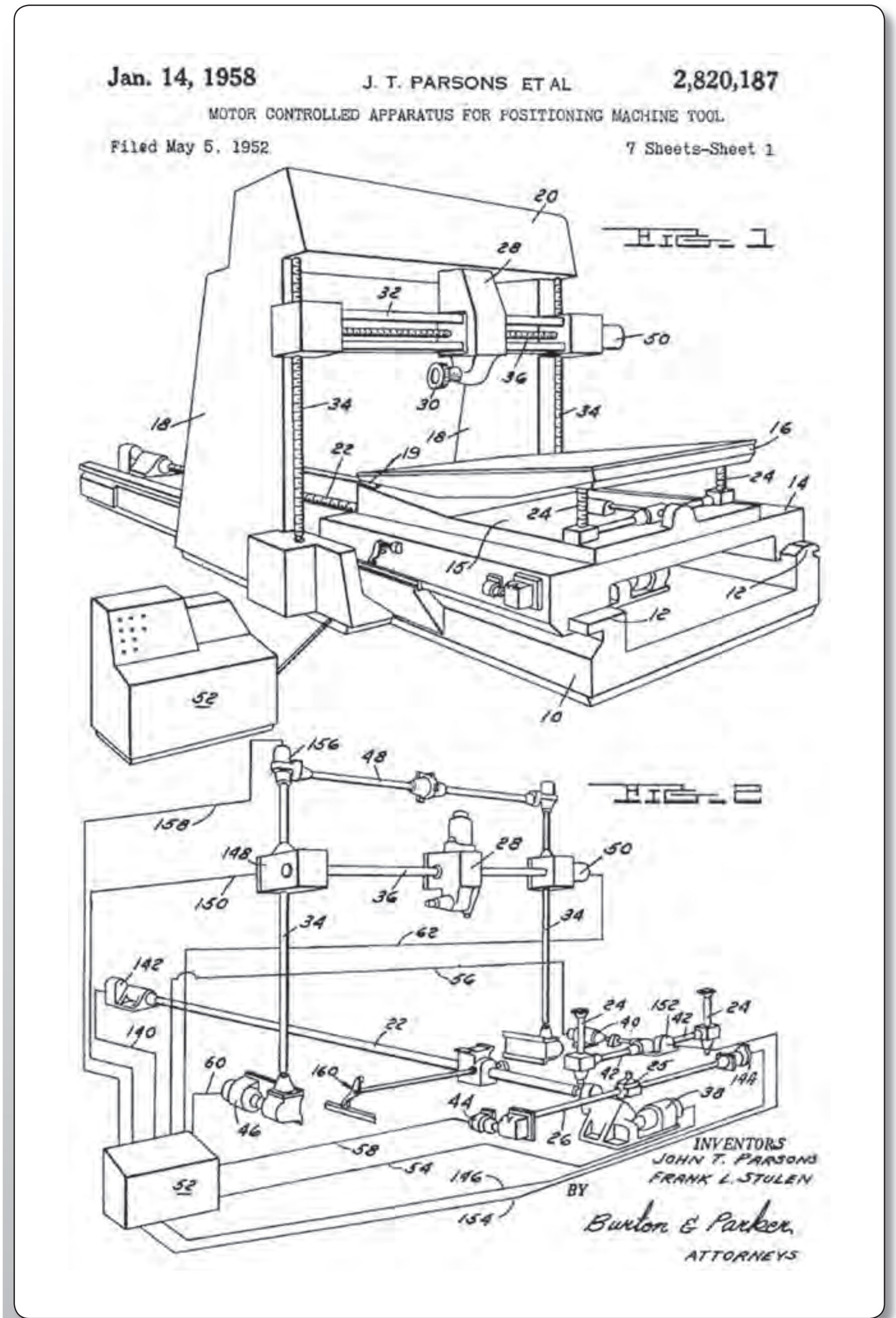

Fig. 2.3.2: Presentation of American patent No. 2,820,187 (Parsons) [www-2]

the patent application for the "numerically controlled servo system" on 14th August 1952. On 4th January 1958 Parsons received US patent No. 2,820,187 (Fig. 2.3.2) and the company sold the exclusive licence to Bendix, IBM, Fujitsu and General Electric companies – all these companies adopted sublicences after they had started the development of their own devices.

MIT machine [www-1]

MIT built gear sets to various inputs through handwheels and drove them by means of roller chains connected to motors. One was always specified for one of three machine axes (X, Y and Z). The associated control unit consisted of five boxes having the refrigerator size. These boxes were together almost so big as the milling cutter which they were connected to. Three of these boxes included the motor control units, one control unit for each motor, and the remaining two ones included the digital reading system.

In contrast to Parsons's original design with punched cards, the MIT design used the standard seven¬ track punch tape for the input. Three of these tracks were used to control various machine axes, while four remaining tracks coded various control information. The tape was read in the box containing also six hardware registers based on relays, two for each axis. At every reading operation, the point read previously was copied to the "initial point" register and the point read newly was copied to the "end point" register. The tape was read continuously and the number in the register increased until the "stop" instruction was read, which was represented by four holes in the line.

The last box included the clock which sent pulses through these registers, compared them and generated output pulses which were inserted between the points. For example, if the points were far away from each other, the output had pulses at each clock cycle. while points arranged near to each other generated pulses only after a few clock cycles. The pulses were sent to the adding register in the motor control units and they were added up to the pulse number every time, when they were received. The adding registers were connected to the digital analog converter which sent increasing power to the motors, while the number in the registers was increasing.

The registers were decreased by means of encoders connected to the motors and to the milling cutter itself, which reduced the number by one for each speed step. As soon as the second point was reached, the pulses from the clock stopped and the motors drove alternatively the milling cutter to the coded position. Each speed step of control elements resulted in the cutting head motion by 0,0005 inch. The programmer could control the cutting speed by selection of those points which were located nearer to each other, which resulted in the slower motion. Or, he selected those points which were farer away from each other, which resulted in the quicker motion.

In September 1952 the system was demonstrated in public in Scientific American. The MIT system was an outstanding