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Original article

Assessment of the safety of use of portable machine tools

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ABSTRACT

The article presents safety issues related to on-site machining with the use of portable machine tools. Their advantage is the possibility of machining elements at places in which they are used. This especially refers to large-size constructions, welded elements and any items whose disassembly is technically difficult.

The authors present tasks performed by the operators of portable machining equipment, working conditions, construction and characteristic features of portable machine tools on the example of a portable boring machine, milling machine and flange facing machine. The presented characteristics can influence the safety of work with these machines. The information given in the article were used to asses risk at the position of a portable machine tool operator. The assessment was conducted using the Risk Score method taking into account four stages of using portable machine tools, i.e. transport, assembly/disassembly, machining and maintenance.

The result of the conducted risk analysis is the proposal of possible risk reducing actions. Due to the specificity of the operation of portable machine tools which significantly impedes the development of a machine tool which would be safe in and of itself, the proposed actions refer mainly to organisational solutions.

The work presents also the thesis that it is possible to decrease the risk at this position thanks to the use of numerical control in a portable machine tool. Such a solution may reduce exposure to some identified threats. The issue is presented on the example of a prototype of a portable flange facing machine developed in the Institute of Mechanical Technology ZUT in Szczecin.

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KEYWORDS

portable machine tools, portable machining, on-site machining, risk analysis, safety

Introduction

The intensive development of such sectors as energy production and civil engineering puts pressure on engineers to build/create increasingly bigger and more technically advanced constructions frequently in field conditions. Challenges faced by these engi-

neers are serious because firstly building such constructions in difficult conditions is an arduous task in itself, secondly the logistics related to constructing large-size technical objects is complex, and thirdly there is the maintenance and servicing such objects.

Portable machine tools turned out to extremely useful in solving such technical problems as they enable the assembly of large constructions or the reconstruction of large elements of technical installations at the places where they operate/function. This is why in many cases portable machining equipment is a good alternative for stationary machining tools. In the recent years on-site machining, the so called portable machining, has gained numerous supporters and the use of such machines is becoming more and more common.

Although in the Polish job description search engine one can find jobs related to operating machines (machining tools operator, cutting tools operator, numerically controlled machines operator, unit-construction machine operator) [Wortal… n.d.], the information about the jobs can refer to portable machine tools only to some extent.

The analysis of repairing faults of large technical installations allows to observe that the working conditions of the machines and consequently their operators are markedly different. The stages of removing a technical problem using both stationary and portable machines is presented visually in Figure 1. The scheme takes into consideration also the participation of machine operators at particular stages. It should be noted that the operators of portable machines are present practically at each stage of the process, which certainly influences their qualifications as well as work safety.

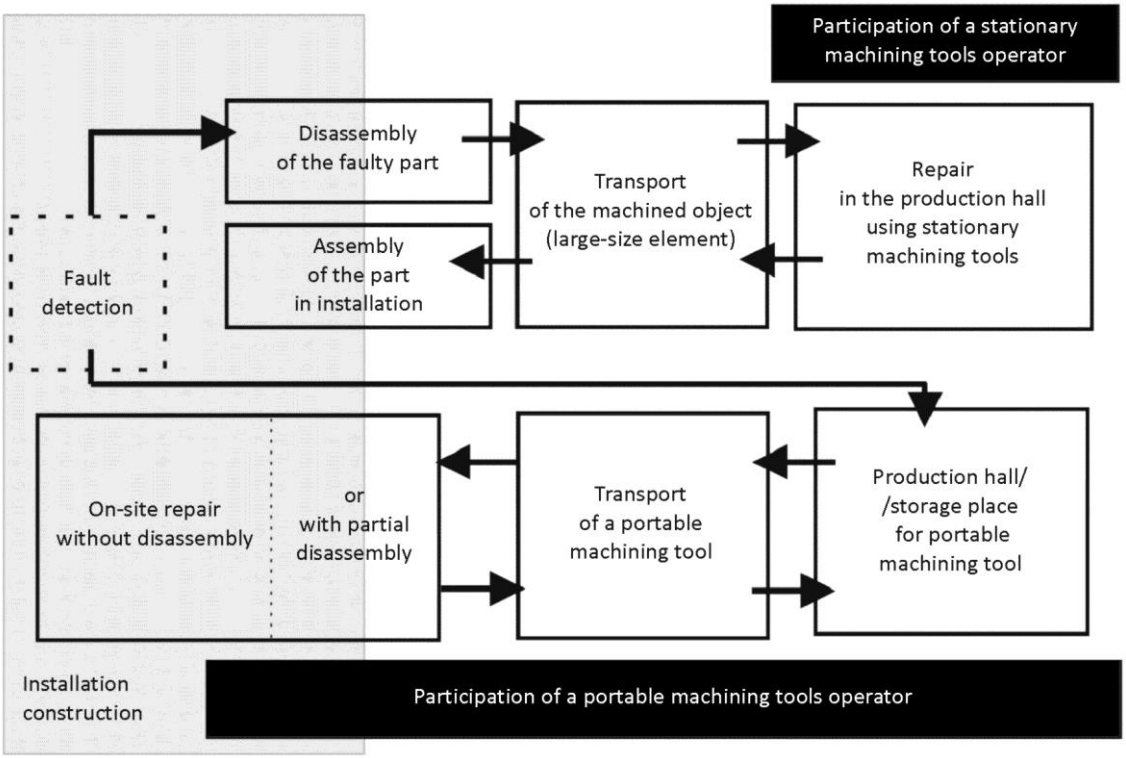

Fig. 1. Fault removal stages with the use of stationary and portable machining tools
Source: [Own elaboration].

1. Position and job description of portable machine tools operator

The job of a portable machine tools operator requires universal qualifications and an extensive knowledge of machining technologies and metrology. The basic task of the operator is performing the required machining at the place where the machined object is installed. A very important element influencing safety can be the irregularity of orders the preparation of the fault removal process every time taking into account technical conditions (changeable working conditions, machined object, requirements).

Depending on a production order and the organisation of work, the operator can perform activities related to the transport of a machine tool to the place of operation, fixing the equipment on the machined object and later disassembly of the equipment, positioning the machine with regard to the object, controlling machining and maintenance. The success of each of these stages depends largely on the operator's experience and skills.

The transport of the machine tool to the site of operation is the first stage of order processing. It encompasses both distant transport (e.g. between plants), i.e. the delivery of secured equipment and other devices using a delivery vehicle, and also the transport on the premises of the ordering plant, which due to the weight of the equipment usually requires short distance transport and lifting slings.

The next important stage, vital for the further process, is the assembly of the machine on the machined object. Operator's responsibilities encompass: selection of a machine tool type, the way of fixing which will be most appropriate for the task and the machined object. In industrial practice there are numerous fixing systems which are an integral part of the machine or belong to accessory equipment [Pawelko et al. 2013]. A frequently used solution is welding the assembly elements of the machining tool to the machined object. The accuracy of the shapes and dimensions of machined tools is highly influenced equipment positioning. Activities related to assembling the machine tool on the object in the case of portable equipment cause numerous problems and are time consuming. The operator (frequently supported by metrologists/surveyors) precisely sets the machine tool with regard to the machined object.

The machining itself is also time consuming and requires constant attention of the operator. Possible dimension or shape related errors must be corrected after machining and the earlier machine positioning. In the case of excessively high degradation of machined objects (when their reconstruction of regeneration is necessary) surfacing by welding of the material is used.

The key element in the correct and at the same time safe operation of equipment is well planned and systematic maintenance conducted in accordance with manufacturer's requirements.

To sum up, operator's safety during the use of portable machine tools to a large extent depends on external factors (e.g. atmospheric). Organisation of work and, first of all on production processes themselves.

2. Particular characteristics of portable machine tools influencing safety of use

Portable machine tools when it is impossible or too expensive to use conventional machining with stationary equipment. This is the case when it is necessary to work on large-size elements which are very expensive to transport and the cost of downtime of the installation is very high or, when the installation is complex, the disassembly of some elements is technically very difficult. Such tools are also used when high shape and dimension accuracy is required after welding elements. This specificity of work results in the fact that machine tools are considered special equipment and their construction systems strictly depend on the type of machined objects. This is why most frequently they are machines dedicated to particular types of products, such as flange facing machines.

The most important characteristic of portable machine tools is their transportability, this is why the main construction requirements are related to the minimisation of their mass. This translates into the kinematic mobility structure and the power of drives (small power drives are used in such tools). Due to the limited operation space, constructions consist only of components necessary to perform machining tasks: drives (electric, hydraulic, pneumatic), transmission mechanisms, feed rate axles (1 in the case of boring machines, 2-3 in the case of milling machines), rifling heads, mounting elements to fix the device to the machined object, elements facilitating transport. The construction and use of portable machine tools are presented on the example of a portable boring machine (Fig. 2), a milling machine (Fig. 3) and a flange facing machine (Fig. 4).

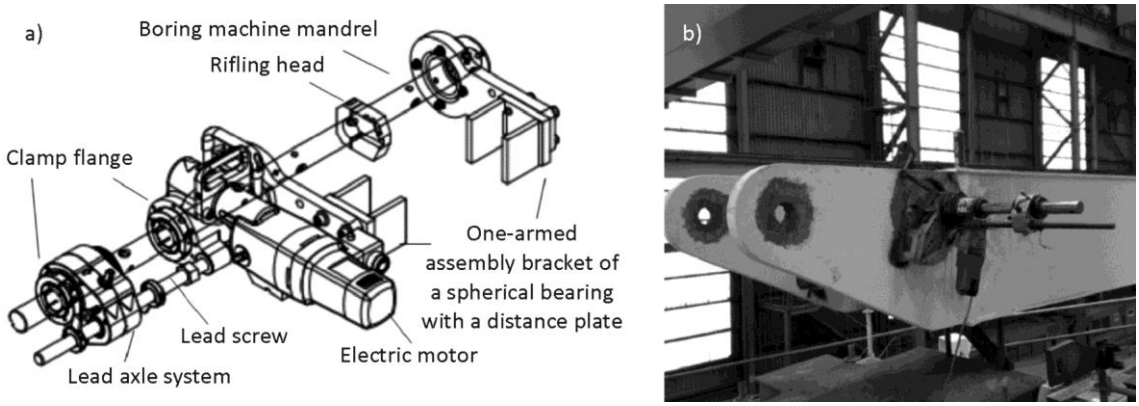

Fig. 2. Portable boring machine: a) construction on the example of BB4500; b) boring holes, an example with partial disassembly of the machined object
Source: a) [Marketing materials [Our products n.d.]], b) [Marketing materials [K.S. Boring… n.d.]].

This simplified construction has some advantages. It can be more resistant to faults during transport and also difficult surrounding conditions. However, it may have a negative impact on the operator's comfort and time of work. It is also necessary to use additional equipment, such as measurement devices allowing to position a portable machine tool on a machined object.

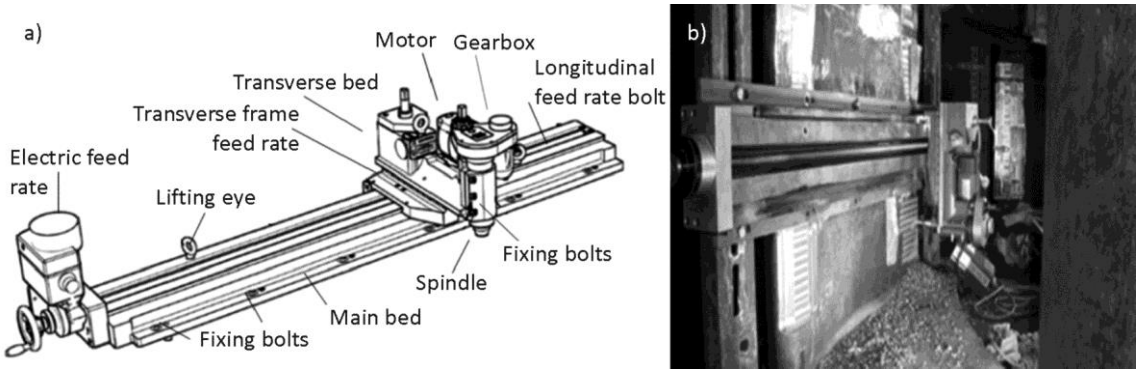

Fig. 3. Portable milling machine: a) construction on the example of PM4200; b) milling a water turbine blade, an example without the disassembly of the machined object
Source: a) [Marketing materials [Our products n.d.]], b) [Marketing materials [K.S. Boring… n.d.]].

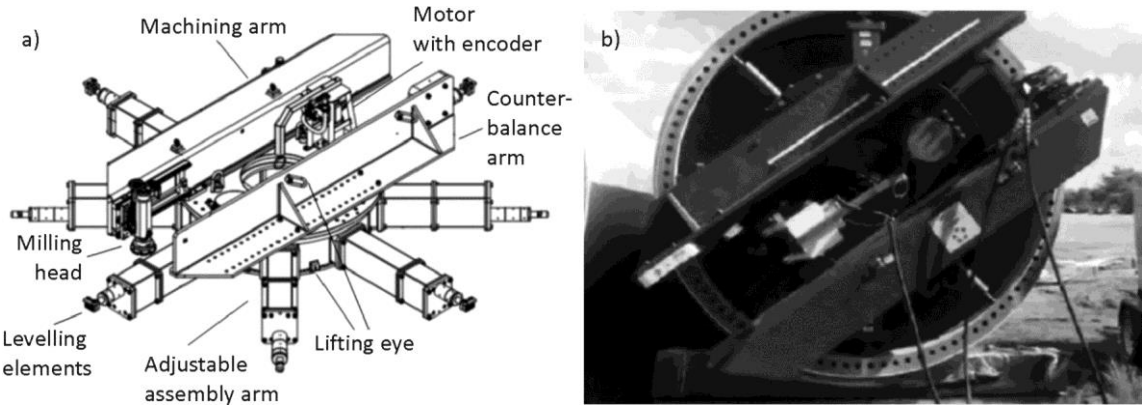

Fig. 4. Portable flange facing machine: a) construction on the example of PM4200; b) milling flange face, an example of the construction of new installation
Source: a) [Marketing materials [Our products n.d.]].

3. Safety assessemnt of portable machine tools operation

Threat assessment was conducted using the Risk Score method. It allows to identify the possible occurrence of an accident and is based on the qualitative probability assessment of the occurrence of threats (P), damage occurrence degree (S) exposure to threat (E) [Romanowska-Slomka and Slomka 2008]. The analysis was conducted in accordance with the methodology presented in Figure 5.

The result of the conducted analysis is the register of threats presented in Table 1, it includes the assessment of risk level at the particular stages of the fault removal process with the use of a portable machine tool. In the analysis the whole cycle of actions related to the service of these machines was taken into account. Special care was taken to include the largest number of possible events remembering, however, about the uniqueness of orders and machining tasks.

Symbol "◊" refers to threats at an acceptable risk level, symbol "○" permissible risk level, while symbol "●" threats representing unacceptable risk level and it is absolutely necessary to take measures to decrease it. The letters T, M/D, O, K, refer to particular

phases of using portable machine tools: Transport, Assembly/Disassembly, Macining, Maintenance, respectively.

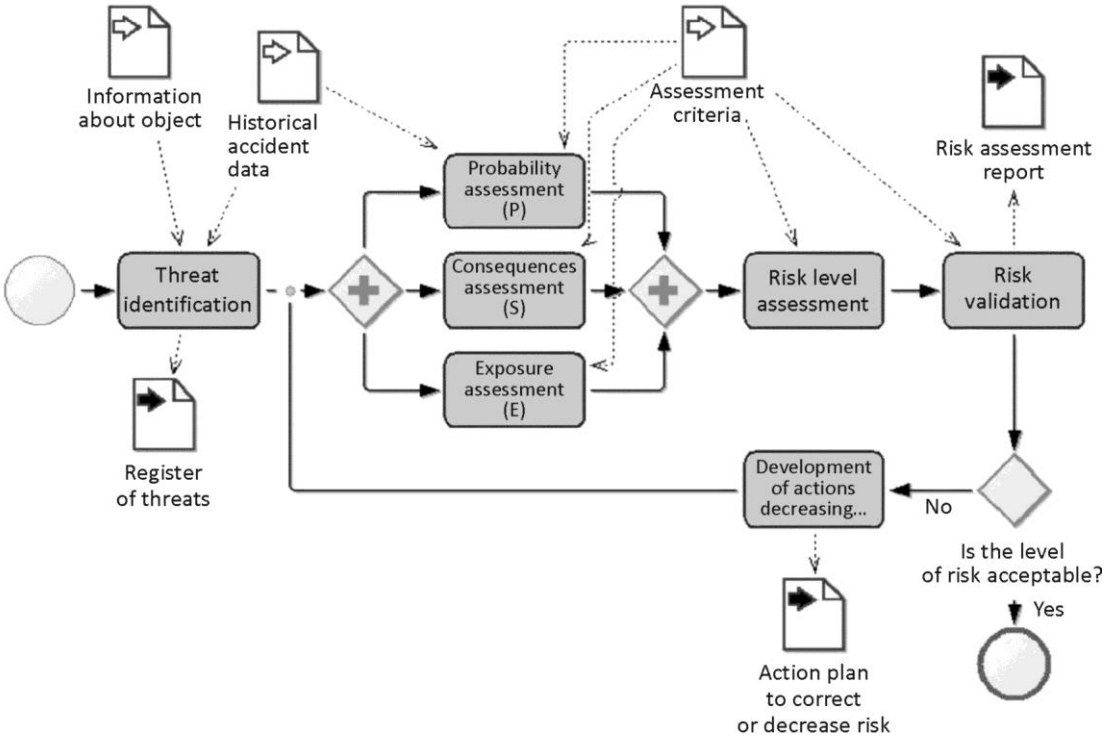

Fig. 5. Procedure stages in the Risk Score method
Source: [Own elaboration].

Table 1. Register of threats with risk level assessment in the particular phases of the fault removal process

	Threats	**Sample events / causes**	**Possible consequences of events**	**S*E*P = R Risk level**			
				T	**M/D**	**O**	**K**
1	Displacement of materials, falling elements	Hitting against elements of a machine or falling elements during transport and relocation of a machine	Contusion, dislocations, bruises, crushed limbs	7*6*6 = 252 ●			
2		Breaking of a lifted load (working at heights)	Head injuries, crushed limbs and other body parts, death	15*2*3 = 90 ○			
3		Crushing by a machine or construction elements, incorrect fixing a machine on a machined object	Head and other body parts injuries, crushed limbs and other body parts, death		15*6*1 = 90 ○	15*6*1 = 90 ○	

	Threats	Sample events / causes	Possible consequences of events	S*E*P = R Risk level			
				T	M/D	O	K
4	Physical dynamic loads	Lifting or carrying excessively heavy loads	Overload of organism, rupture, damage of skeletal system	7*6*6 = 252 ●	7*6*6 = 252 ●		
5	Dust	Covering with dust, powder or chips, working in outdoor conditions, no casings	Irritation of eyes and respiratory system		7*3*6 = 126 ○	7*3*6 = 126 ○	
6	Atmos-pheric factors	Work in difficult conditions, exposure to atmospheric factors	Cold, hypothermia or hyperthermia of organism	3*3*6 = 54 ◊	3*3*6 = 54 ◊	3*3*6 = 54 ◊	
8	Sharp edges	Using sharp tools	Cuts, skin abrasion, contusions		1*6*6 = 36 ◊	1*6*6 = 36 ◊	1*6*6 = 36 ◊
9		During transport		1*6*6 = 36 ◊			
10	Moving elements	Contact with rotating elements	Skin cuts and injuries, crushing upper limbs			7*6*6 = 252 ●	
11	Hydraulic fluid	Leaks of fluids under pressure (hydraulic drives if they are used)	Irritation of skin or eyes, allergies			3*2*6 = 36 ◊	
12	Slippery and dirty surfaces,	slipping /fall, untidiness at the place of work, lack of assigned place of work	Contusions, limb dislocations and breaks, head injuries	3*6*6 = 108 ○	3*6*6 = 108 ○	3*6*6 = 108 ○	3*6*6 = 108 ○
13	Difference of levels	Incorrectly prepared place of work at heights, stumbling, fall from heights	Contusions, limb breaks, disability, death	15*6*6 = 540 ●	15*3*6 = 270 ●	15*3*6 = 270 ●	
14	Electrical current	Electric shock as a result of contact with installation, machines or equipment	Loss of consciousness, palpitation, burns, death, vision, hearing and balance disorders		15*6*3 = 270 ●	15*6*3 = 270 ●	15*1*1 = 15 ◊
15	Explosion fire	Pneumatic drives (if they are used)	Limb, head and whole body burns, death			15*6*0,5 = 45 ◊	
16		Leakage of containers or welder burner defect			15*6*6= 540 ●		

	Threats	Sample events / causes	Possible consequences of events	S*E*P = R Risk level			
				T	M/D	O	K
17	High tempe-rature	Heating elements of machine tools and a machined object during dry machining	Hand burns and burns of other uncovered body parts			1*6*6 = 36 ◊	
18		Open fire, material melted during welding and surfacing by welding			7*3*6 = 126 ○		
19	Ultraviolet and infrared radiation	Electric arch during welding and surfacing by welding	Eyesight damage, irradiated skin on uncovered body parts, skin cancer		7*3*6 = 126 ○		
20	Noise	Portable machine tool, welder, padding machine, other equipment operating nearby	Attention disorders, fatigue, hearing loss		3*6*6 = 132 ○	3*6*6 = 132 ○	
21	Hazardous substances	Substances used to main-tain and clean a machine tool and other tools	Skin irritation, allergies, hand burns				3*2*6 = 36 ◊
22	Physical static loads	Non-ergonomic body position, work in limited space or at heights	Spine and joint pains, degeneration of bones and limbs	7*3*3 = 63 ◊	7*6*6 = 252 ●	7*6*6 = 252 ●	
23	Road accidents	During distant and local transport (using hoisting and hauling equipment)	Contusions and breaks of limbs, disability, death	15*6*6 = 540 ●			

Source: [Own elaboration].

Figure 6 shows the stages of machine tool use and threats characteristic to them. It can be observed that there is an increase in the number of threats at the stage of machine mounting on the machined object, positioning and the machining itself.

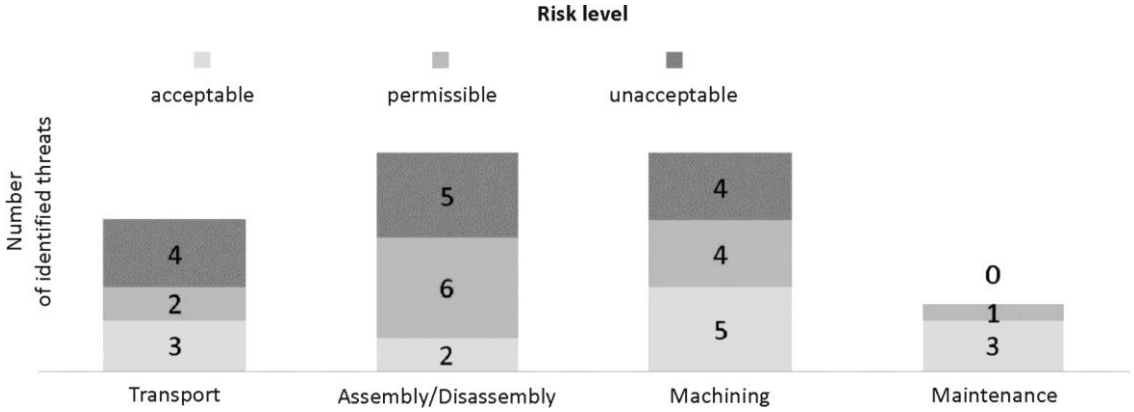

Fig. 6. Risk at particular stages of portable machine tools use
Source: [Own elaboration].

In seven cases the risk level at various stages of portable machine tool use was assessed as permissible and in eight as unacceptable, as a result it is necessary to develop actions reducing risk. First of all it is recommendable to minimise risk using mechanical construction means and control, next mechanical and control protective devices. In further steps, if the risk level is not sufficiently reduced, it is advisable to use means of individual protection, instructions on machinery and a user manual [Dyrektywa 2006/42/WE… 2006; PN-EN ISO 12100]. Table 2 presents proposed actions to reduce risk for threats with the permissible and unacceptable risk level.

Table 2. Proposed protective actions for threats with permissible and unacceptable risk level

	Threats	**Sample events/causes**	**Risk reducing actions**	**S*E*P = R**			
				Risk level after introducing risk reducing actions			
				T	**M/D**	**O**	**K**
1	Displacement of materials, falling elements	Hitting against elements of a machine or falling elements during transport and relocation of a machine	Using attested equipment, acting in accordance with user manual instructions for hoisting and hauling equipment, individual protection means	3*6*3 = 54 ◊			
2		Breaking of a lifted load (working at heights)	Using attested equipment, acting in accordance with user manual instructions for hoisting and hauling equipment, individual protection means	15*2*1 = 30 ◊			
3		Crushing by a machine or construction elements, incorrect fixing a machine on a machined object	Mounting a machine in accordance with user manual instructions, using safety equipment such as safety lines and chains, checking machine stability before starting further actions, individual protection means*		3*6*1 = 18 ◊	3*6*1 = 18 ◊	
4	Physical dynamic loads	Lifting or carrying excessively heavy loads	Acting in accordance with binding standards for transport, use of accessory equipment, teamwork	3*6*3 = 54 ◊	3*6*3 = 54 ◊		
5	Dust	Covering with dust, powder or chips, working in outdoor conditions, no casings	Use of individual protection means (protective glasses, masks)*		3*3*6 = 54 ◊	3*3*6 = 54 ◊	

	Threats	Sample events/causes	Risk reducing actions	S*E*P = R			
				Risk level after introducing risk reducing actions			
				T	M/D	O	K
10	Atmos-pheric factors	Work in difficult conditions, exposure to atmospheric factors	*			7*6*6 = 252 ●	
12	Sharp edges	Using sharp tools	Suitable shoes, cautious behaviour	3*6*3 = 54 ◊	3*6*3 = 54 ◊	3*6*3 = 54 ◊	3*6*3 = 54 ◊
13		During transport	Using safety harness, shock absorbers, ropes*	7*6*3 = 126 ○	7*3*3 = 63 ◊	7*3*3 = 63 ◊	
14	Moving elements	Contact with rotating elements	Checking connections and electric wiring, conducting all repairs by an authorised electrician, using residual-current devices, acting in accordance with user manual and maintenance instructions, using safe voltages in command circuits		3*6*3 = 54 ◊	3*6*3 = 54 ◊	3*1*1 = 3 ◊
16	Hydraulic fluid	Leaks of fluids under pressure (hydraulic drives if they are used)	Fire-fighting equipment, using sensors, attested equipment which is regularly tested (valves, reducers)		7*6*3 = 126 ○		
18	Slippery and dirty surfaces,	slipping /fall, untidiness at the place of work, lack of assigned place of work	Using individual protection means, face shields, gloves, boots*		3*3*3 = 27 ◊		
19			Using specialist protective clothing for individual protection, protective screens		7*3*1 = 21 ◊		
20	Difference of levels	Incorrectly prepared place of work at heights, stumbling, fall from heights	Reducing work time if staff, staff rotation, hearing protectors		3*3*6 = 54 ◊	3*3*6 = 54 ◊	
22			Staff rotation, individual protection means*	7*3*3 = 63 ◊	7*3*3 = 63 ◊	7*3*3 = 63 ◊	

	Threats	Sample events/causes	Risk reducing actions	S*E*P = R			
				Risk level after introducing risk reducing actions			
				T	M/D	O	K
23	Electrical current	Electric shock as a result of contact with installation, machines or equipment	Observing traffic regulations and internal company regulations, using fully operational vehicles with up-to-date hoisting and hauling equipment tests, checking the authorisation of vehicle drivers	15*6* 1 = 90 o			

Source: [Own elaboration].

The specificity of work presented in earlier sections is a significant obstacle in the preparation of a construction which would be safe in and of itself. The actions proposed in Table 2 are mainly related to observing procedures at work and good organisation of work as well as the use of fully operational equipment. An important element in safety management is also the management of staff qualifications and competences.

The safety of use of portable machine tools can be greatly influenced by numerical control. This solution may influence mainly the reduction of operator exposure to some threats and, as a result, the reduction of risk to acceptable or permissible levels. These threats were marked with * and refer to the assembly and machining stage.

The Institute of Mechanical Technology developed a prototype of a numerically controlled portable machine tool dedicated to machining large-size flanges (Fig. 7). The machine is equipped with 5 numerically controlled axels, it also has the functions of a measurement device. The concept justified mainly from the economic perspective, especially in terms of the time consuming nature of activities related to mounting and positioning a machine tool on a machined object.

The use of numerical control in this type of machines allows to eliminate the activities connected with positioning them and simplify mounting. After mounting the machine, the machined object is measured in the machine tool system, which allows to determine the positioning error. Instead of mechanical corrections of the machine position with regard to the machined object, it is possible to use software correction of the motion path of a cutting tool.

The presented concept has both advantages and disadvantages. The solution adversely affects machine tool mass and its size. One may also feel reluctant to use this solutions because of some delicate parts (sensors), which may reduce machine resistance to mechanical damage (e.g. during transport). It also requires its operators to possess additional qualifications and skills.

However, the work safety benefits of the presented concept are as follows: shorter exposure to static loads, e.g. during mounting and positioning, noise, the operator is "moved away" from moving elements of the machine during the machining process (remote control, possibility of shape machining without the necessity to manually change the length of a cutting tool).

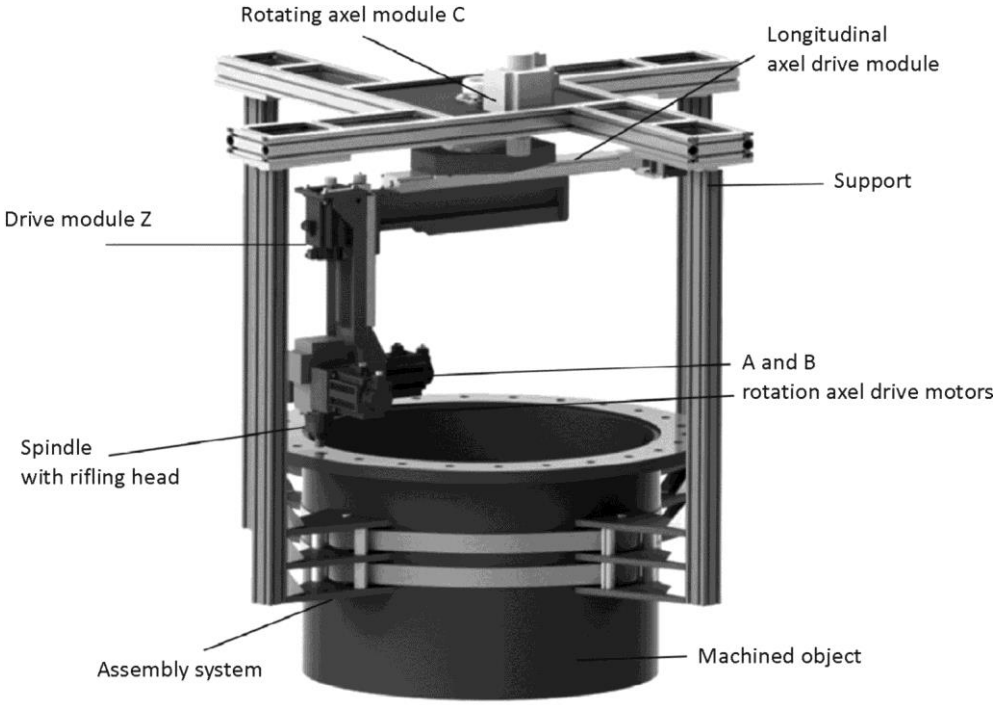

Fig. 7. Numerically controlled portable flange facing machine
Source: [Pawelko 2013].

Conclusion

Machining large-size elements is a complex issue. Such tasks can be performed using portable machine tools. Relatively simple technologies and changeable working conditions significantly influence the work safety of operators using these machines. The conducted analysis has shown that the majority of threats occur during the mounting and positioning a portable machine tool on a machined object. The specificity of this work makes it difficult to use construction solutions which would be safe by nature. The safety improvement of portable machine tool use can be obtained by the application of numerical control, which can reduce risk level especially at the mounting and positioning stage by shortening the operator's exposure to threat factors.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

ORCID

Monika Nowak – The author declared that she has no ORCID ID's

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