# APARATURA
## BADAWCZA I DYDAKTYCZNA


# Equipment for laser beam microinterference in a water jet


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**Keywords:** microjets, micro-processing, microinterference



**ABSTRACT**

Subject of the paper is development and construction of a usable model for studies of micro-interference with a laser beam in water fibre on various materials, including thin and thick foil, human and animal tissue. The method consists in introduction of a laser beam into a 50-200 µm-diameter water jet flowing out of a nozzle under pressure of 5-30 MPa. The water jet, acting as an optic fibre, carries energy to the material processing or a tissue interference site. It is important that the beam (energy) is for the whole time concentrated along the distance between the front of the head and a point of approx. 50 mm away, and that is a working area. Experiments in micro-interference in tissues are of interest for specialists in the field of medicine, cosmetology, veterinary medicine and biology.


## Aparatura do mikroingerencji wiązką lasera w strumieniu wody


**Słowa kluczowe:** mikrojety, mikroobróbka, mikroingerencja



**STRESZCZENIE**

Przedmiotem artykułu jest opracowanie i budowa stanowiska do badań mikroingerencji promieniowania laserowego w otulinie cieczy w różnego rodzaju materiały, takie jak cienkie i grube folie, tkanki ludzkie i zwierzęce. Metoda polega na doprowadzaniu do obrabianego materiału wiązki promieniowania laserowego skoncentrowanego w strumieniu wody o średnicy 50-200 µm wypływającym z dyszy pod ciśnieniem od 5 do 30 MPa. Strumień wody, spełniający rolę światłowodu, doprowadza energię do miejsca obróbki materiału bądź miejsca ingerencji w tkance. Istotnym jest to, że strumień (energia) jest skoncentrowany od czoła głowicy do odległości ok. 50 mm i to jest obszar roboczy. Zainteresowanymi eksperymentami nad mikroingerencją w tkanki są badacze z obszaru medycyny, weterynarii, kosmetologii i biologii.

## 1. INTRODUCTION

Lasers are currently widely used in production processes and material processing. Particularly, a laser beam is used for cutting, welding, thermal processing and marking purposes.

Cutting applications involve also a competitive method of water jet, offering similar precision and smooth cutting edges. The method is used principally for cutting metals, including stainless and tool steel, aluminium, titanium, as well as for ceramic materials. Effective cutting with a water jet with the addition of an abrasive is achieved in devices with cutting head producing a 0.2 – 1.0 mm-wide jet at the velocity of approx. 1000 m/s. To achieve that kind of jet, nozzles made of the hardest materials, such as diamond or sapphire, are used.

Combination of both methods by introduction of a laser beam into a water jet offers some new application options. Studies on the practical use of the method were initiated in 1998 at the Polytechnic University in Lausanne, with high-power lasers. Absence of a necessary laser beam focus on the processed element is an important advantage of the method, allowing much higher penetration depths.

## 2. PURPOSE

Purpose of this elaboration is to present a construction principle of a system for optic fibre laser processing system, using a laminar-flow jet of liquid. Low-power laser radiation is used (max. 2 W) and a laminar water jet diameter below 0.15 mm. The solution is intended for all micro-processing applications where conventional methods requiring focusing on the processed object is impractical. A possibility of working at any distance from the head (within the range of laminar flow of liquid) opens some interesting application options in microsurgery and cosmetics, particularly when an appropriately selected physiological fluid is used as a carrier, instead of water.

## 3. THE SOLUTION CONCEPT – STRUCTURE OF THE DEVICE

The elaboration aimed at construction of a usable model for studies of micro-interference with a laser beam in water fibre on various materials, including thin and thick foil, human and animal tissue. A need for that kind of device was identified during studies of microprocessing methods of silicone plates, realised in 1999-2000 at the Institute of Precise and Biomedical Engineering of the Warsaw University of Technology (IIPiB), as a part of the Priority Program Modern Technologies.

The solution consists in introduction of a laser beam into a 50-200 µm-diameter water jet flowing out of a nozzle. A pressure of 5-30 MPa was used. The water jet, playing the role of an optic fibre, guides the laser beam to the processing site. A review of the state of world technique in that respect indicated that studies on that kind of processing were carried out only at the Polytechnic University in Lausanne [1]. Early information on that subject surfaced in 1999 [2], and the SYNOVA company, a part of the engineering background of the Polytechnic, offered devices based on the new method, for application in high-energy processing, probably of military and space technology elements. However, the cost of that kind of equipment was very high.

The discussed technology is a new way of material processing, potentially applicable in various technical fields. Currently there is still a need for that method in cutting of silicone plates for diodes and power thyristors, as well as in production of semi-conductive detectors and sensors made of brittle materials (e.g. silicon, germanium and gallium arsenide), and also for other elements of micro-systems. A search for further applications is also purposeful (biomedical, military techniques, etc.).

Work carried out at the Institute (IIPiB) and in companies Telesystem Mesko and Solaris Optics SA in 2000-2005 allowed development of theoretical basis and preliminary laboratory tests regarding a possibility of introducing a laser beam into a processed material with a thin stream of water, using the phenomenon of a complete internal reflection [3, 4].

Operations continued in 2012-2013 in COBRABiD [5] demonstrated a real opportunity of domestic development of modern laser technologies based on micro-interference of a laser radiation in a jet of liquid. However, to be able to prepare an implementation blueprint, several basic problems have to be solved first. An appropriate application test station is one of them. First construction works and nozzle selection were done using the model set, presented in the Figure 1.

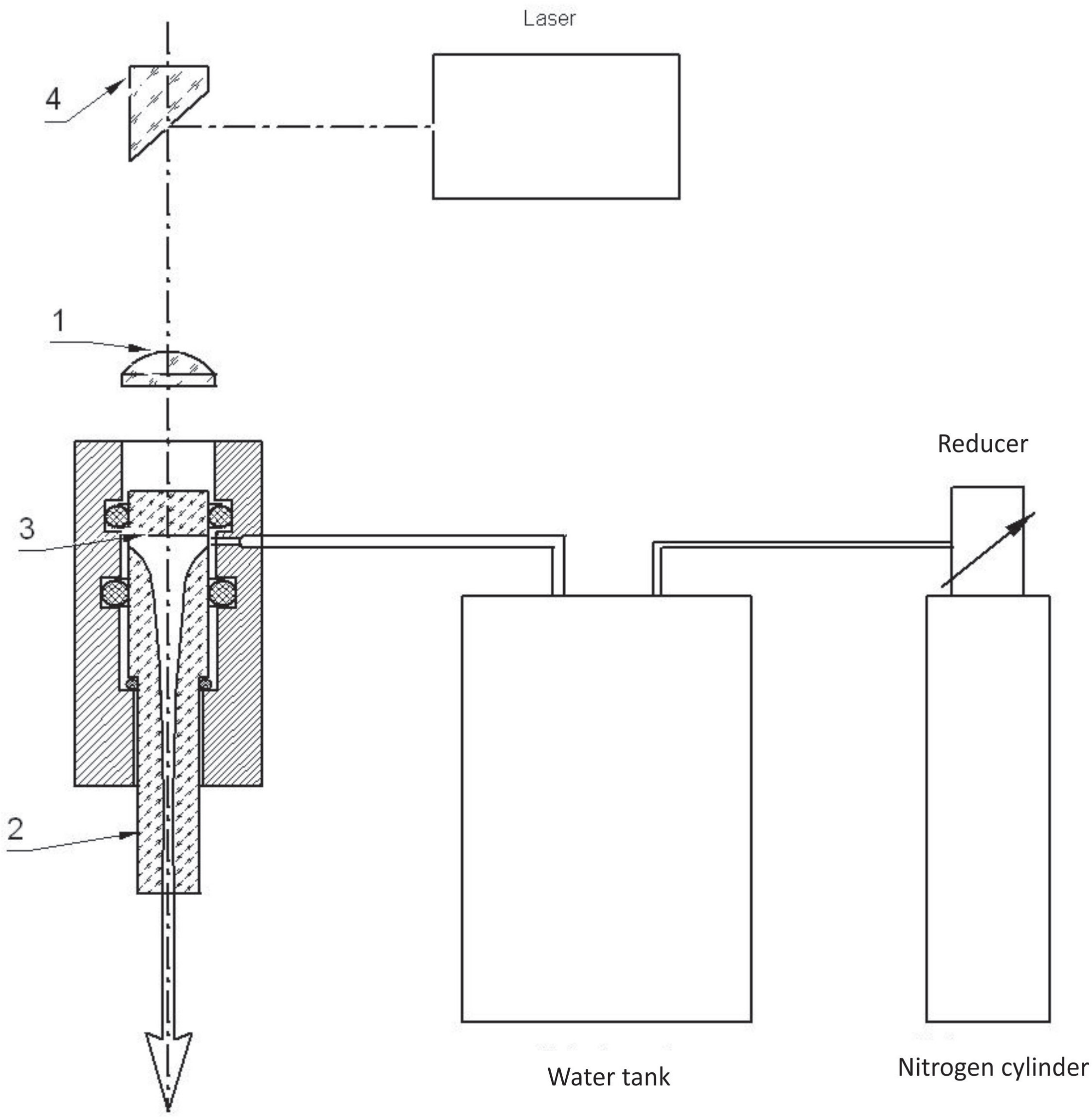


**Figure 1** Head power system with optic elements.
1 – flat-convex lens, 2 – glass or steel nozzle, 3 – glass cylinder (plug), 4 – prism

Development of a station based on laser diodes was assumed. Diodes would allow interference with radiation of variable wavelength within the visual spectrum and near infra-red, a smooth power regulation and transmission of the radiation in an optic fibre, with elimination of an optic system and simplification of the device (Fig. 2). A maximum diode power of 2 W was assumed and pumps-less liquid (water) transport, using a pressure method. The working liquid feeding system consists of: pressure source from a common cylinder with liquid nitrogen, a reducer with control manometers, and a pressure tank with a manometer for control of the output pressure. Compressed nitrogen is supplied to the tank "from above", over the surface of the liquid. The liquid is supplied "from the bottom". That way it is pushed under pressure and supplied through a cut-off valve to the working head containing the laser beam and liquid jet coupling system. General view and cross-section of the tank are presented in Figures 4 and 5.

## 4. WORKING NOZZLES

To introduce a laser beam into a water jet playing the role of an optic fibre, an appropriate capillary tube is necessary. A nozzle should allow introduction of a water jet and an optic fibre, and should form a laminar, low-diameter water jet (approx. 0.1 mm).

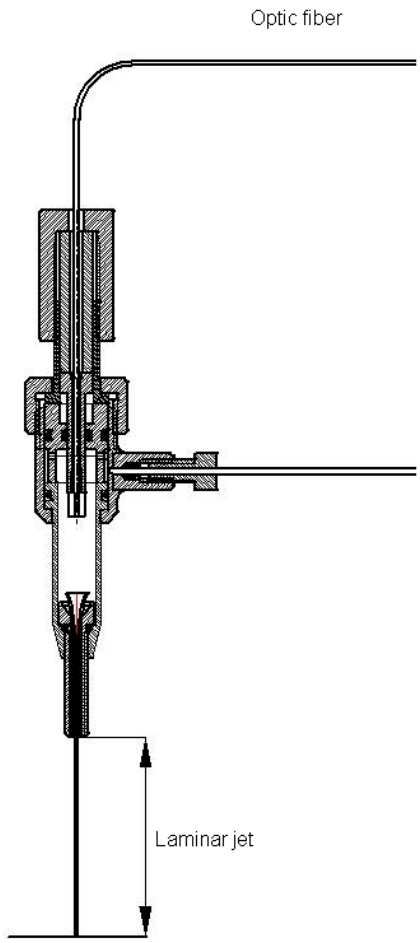


**Figure 2** Introduction of a laser beam to the head through the optic fibre

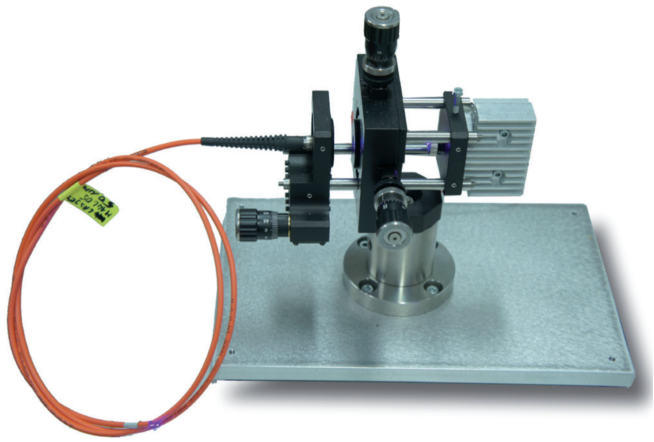

**Figure 4** The laser beam to optic fibre introduction system

**Figure 5** The general view of the tank (photography)

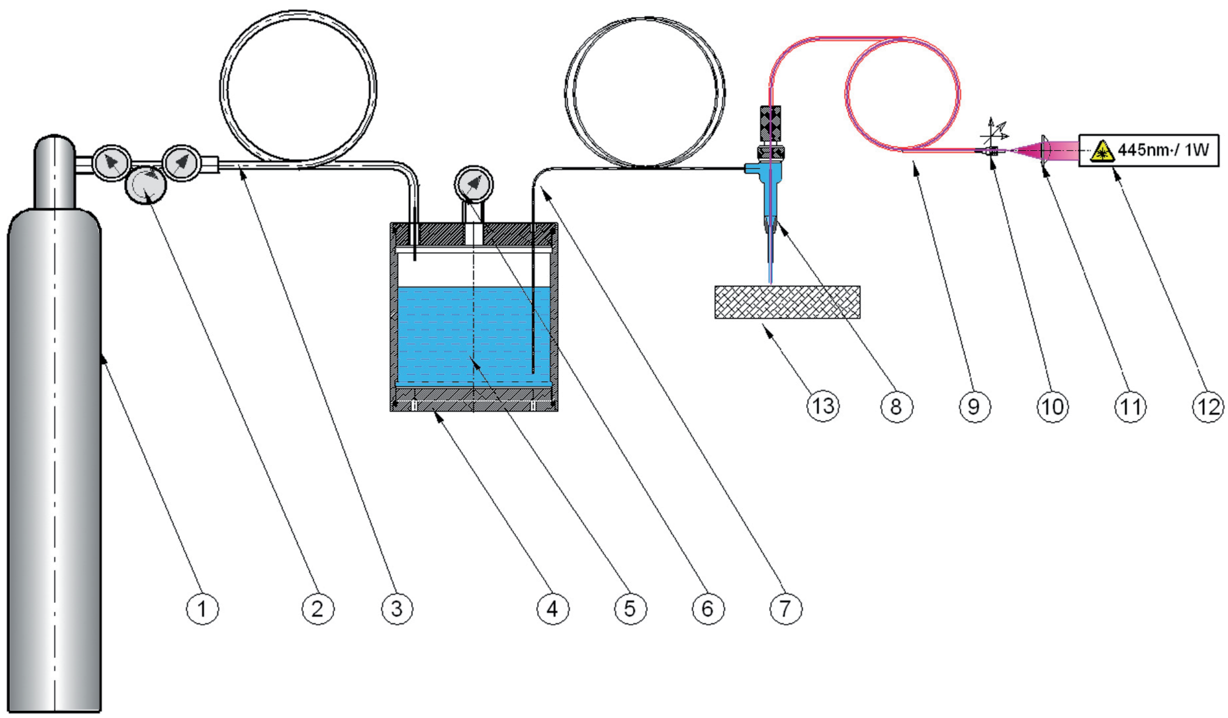


**Figure 3** The general scheme of the test station. Legend: 1 – A cylinder with pressurised nitrogen; 2 – Manometers with a valve; 3 – Pressure tube; 4 – Pressure tank; 5 – Liquid (water); 6 – Manometer; 7 – Liquid supplying capillary tube; 8 – Working head; 9 – Optic fibre; 10 – XYZ manipulator; 11 – An optic system for coupling of the laser beam with the optic fibre; 12 – A laser (445 nm, 2 W)

Therefore it has to be a nozzle of variable internal diameter and conoidal shape – a bottleneck.
In that kind of nozzle, decreasing cross-sectional surface is accompanied by reduced pressure of liquid, with a simultaneous increase of its velocity. Pressure and outlet diameter parameters of the capillary tube were selected so that to obtain a section of water jet free from turbulence, as long as possible.
The head construction assumptions provided that the tip with the capillary tube will be replaceable, and will contain also a replaceable mount with a capillary tube. Those elements are presented in Figures 6 and 7.
Initially, capillary tubes made of thin-walled silicate glass were used, that were replaced later on by tubes made of borosilicate glass. Also prefabricated capillaries were used, available in the market and used in biological research.
Laser radiation exiting the optic fibre should be introduced to the water jet with as high efficiency as possible. For that purpose the side surface of the capillary tube was initially covered by a layer of silver, which was then replaced by a layer of aluminium, applied by vacuum evaporation.
The other factor influencing the efficiency of introduction of a laser beam into a water jet is thickness of the wall of the capillary exit section. The thickness by the given exit opening of the capillary tube should be as low as possible. For the produced capillary tubes with exit openings of 100-300 micrometers, the wall thickness was several dozens of micrometers.
Prepared capillary tubes were glued into mounts and cemented during the gluing procedure.

## 5. HEAD PRODUCTION AND TESTS. RESULTS.

Currently, both laser beam and water jet (water-abrasive) cutting methods are used by the industry. Lasers offering power of 50 W or higher and deep infra-red radiation, from 250 to 1000 nm,

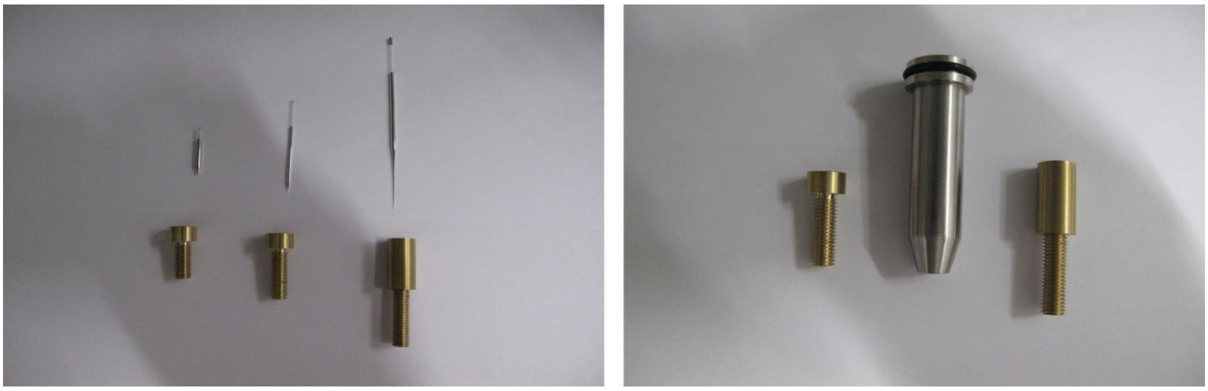

**Figure 6** Construction of the tip and capillary tube mount

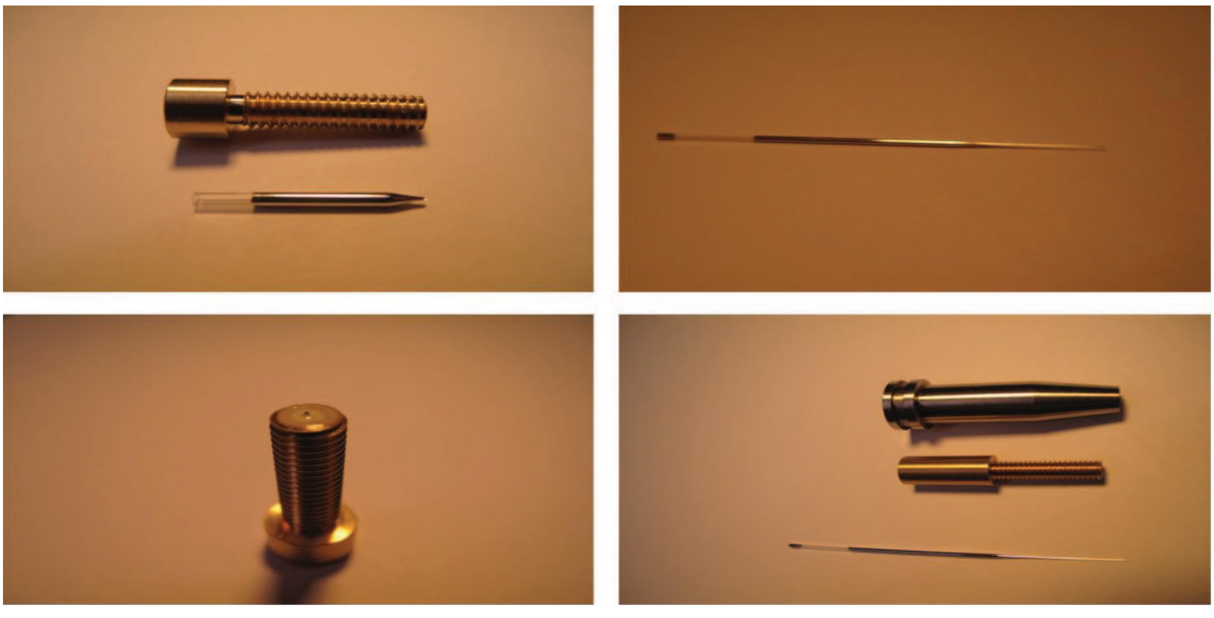

**Figure 7** Nozzles and capillary tubes used for formation of a laminar water jet and introduction of a laser beam

are used, with nozzles formed in synthetic diamond (no information regarding the production method, so far). Involving introduction of a visual range laser beam into a liquid jet forming an optical fibre may offer some interesting practical applications.

The key problem in realisation of the task is to construct a head that would allow production of a small-diameter laminar jet (approx. 0.1 mm) and introduction of an intensive laser beam within. The length of the laminar water jet depends on the application area, and it seems that it should not be less than several centimetres.

Studies on propagation of a laser beam in a laminar water jet were initially carried out using the set presented in the Figure 1. The laminar water jet of approx. 0.1 mm diameter was obtained using a glass capillary covered with Al. The laser beam was directed to the capillary tube using a mirror and focused at the capillary entry point using a lens. The head was closed with a BK 7 glass window covered with an anti-reflexive layer. The system contained several optical elements requiring frequent adjustment during the study. That solution resulted in high susceptibility of the system to dysregulation, and consequential low practical applicability. To eliminate those drawbacks, an optic fibre was used in place of the directing and focusing optical arrays. The head construction presented in the Figure 9 was developed for that purpose. In its upper part there are fixing and optical fibre-tightening elements, and in the lower part there is a replaceable tip con-

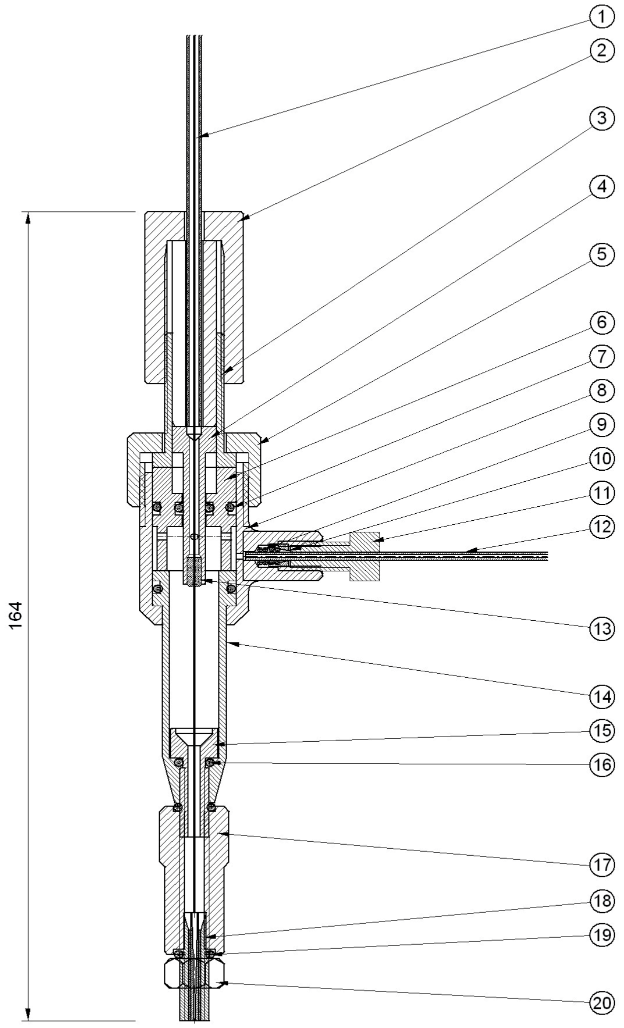


**Figure 8** Working head.
A detailed list of parts of the working head presented in the Figure 8:
1 – A multi-mode optic fibre M14L, with core diameter of 50 micrometers and the coat diameter of 125 micrometers; 2 – Regulation sleeve; 3 – Guiding sleeve; 4 – Passage tube; 5 – Closing ring; 6 – The chamber distance-setting sleeve for liquid introduction;
7 – O-ring 14x1.8; 8 – Liquid introduction chamber;
9 – O-ring 1.5x1.1; 10 – Tightening cone;
11 – Capillary passage; 12 – Steel capillary Φ 1.5 mm;
13 – Silicon gasket of the optic fibre; 14 – Intermediate chamber; 15 – Out socket with the M6 thread;
16 – O-ring 4.5x1.8; 17 – Socket for tips with capillaries;
18 – Replaceable capillary in the M6 body;
19 – O-ring 4.5x1.8; 20 – M6 nut

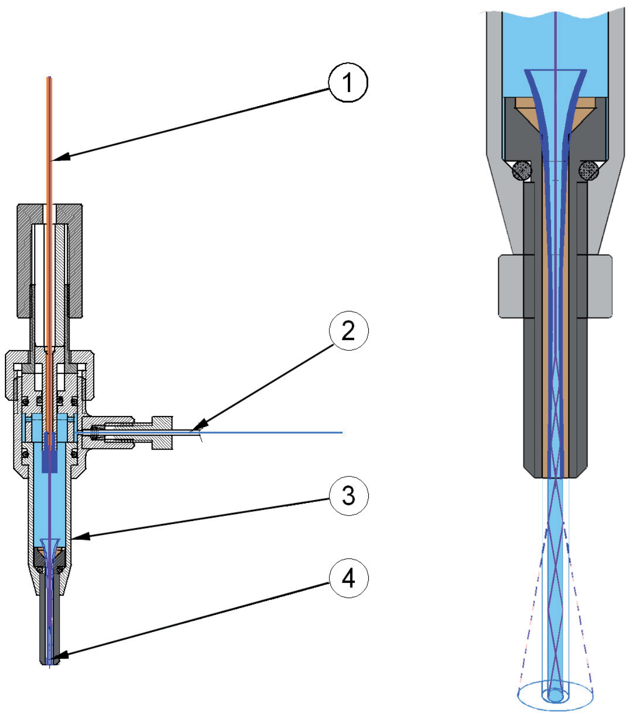


**Figure 9** Schematic solutions of the working head and the principle of a laser beam introduction to the water jet through an optic fibre.
Markings adopted for the Figure 9:
1 – Optic fibre (core diameter 50 micrometres, coat diameter 125 micrometres);
2 – Water supplying capillary tube;
3 – Working head chamber;
4 – Outlet capillary tube

taining the capillary tube with a glass nozzle. That construction allows easy replacement of capillaries, which facilitated various experiments.

Capillary tubes presented in the Figure 7 were used for tests. Layers of Al and Ag were vacuum evaporated on the external surface of capillary tubes. The capillaries were hand-made, with internal diameter of the nozzle at the exit ranging from 0.08 mm of 0.25 mm.

Capillaries were glued into mounts and then fixed in sleeves constituting replaceable head tips. The sample capillaries and tip elements are presented in Figure 7.

Tests performed using heads with 0.1-0.2 mm outlet diameter capillaries allowed production of a laminar jet of up to 60 mm length, which is sufficient for majority of applications. Efficiency of the system (50%) may also be deemed sufficient. However, those parameters should be subject to further tests and optimisations.

## 6. WORK STATION

Conditions: 230 V power supply with surge current protection (a UPS). Pure water (preferably deionised and demineralised). Protective goggles are recommended for users. Results: A laser beam inside a 6 cm-long water jet and efficiency about 50% (the ratio of generated power to emitted power) was achieved. The photography of laser radiation inside laminar water stream is shown on Figure 11.

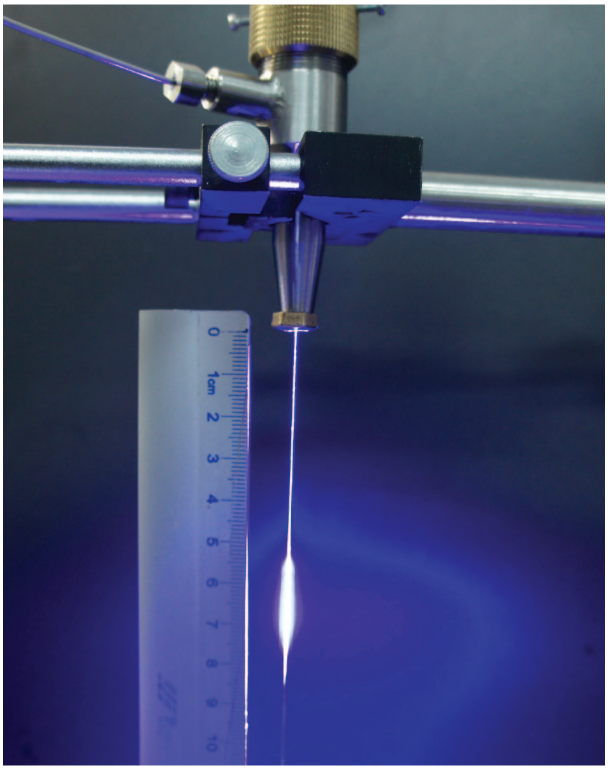

**Figure 11** An approximately 53 mm-long laminar jet

Possible penetration through a 1 mm layer of PU foil within 30 seconds, wood veneer within 30 seconds, muscle tissue (dark red) within 20-50 seconds, fat within 30 seconds.

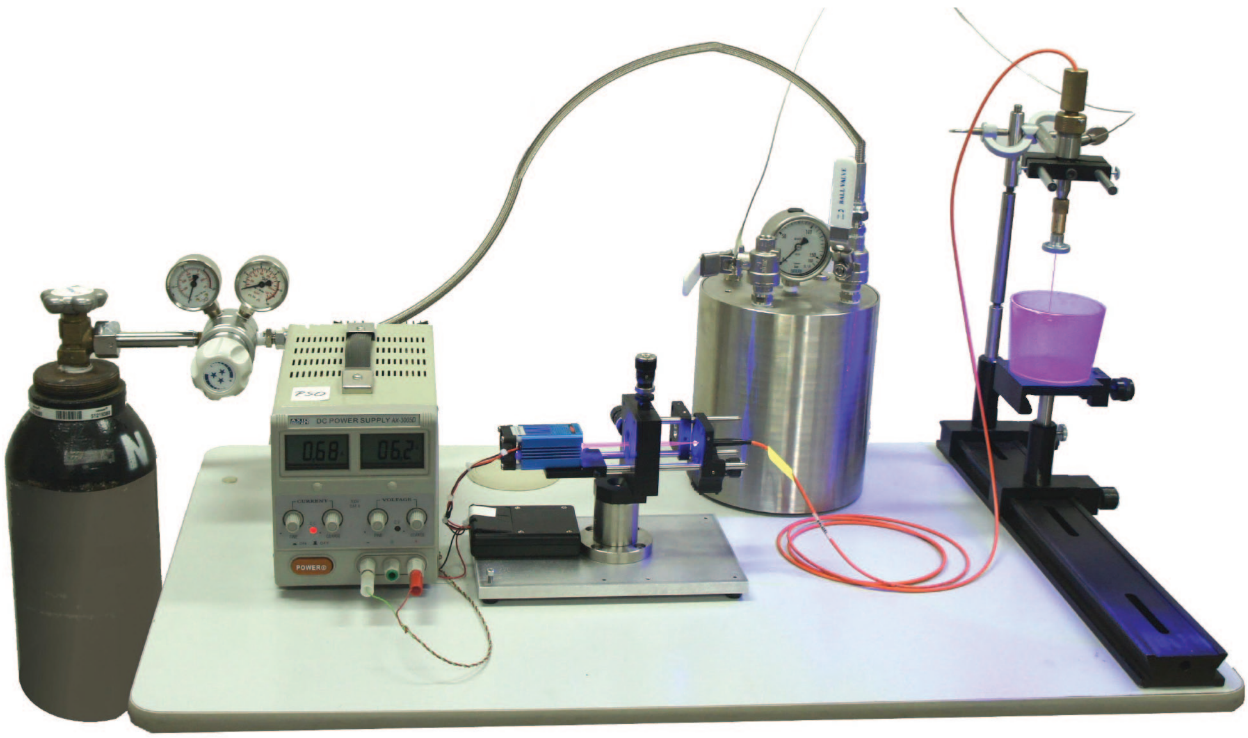

**Figure 10** The general view of the test station

Features and parameters of the station:
– The water jet is translucent for the laser beam; radiation does not cause heating or evaporation; only a contact with the material triggers the heat, leading to the thermal interference and evaporation.
– The jet offers cooling of the material, thus protecting the cut material from overheating; heat dissipation may be regulated through the evaporation adjustment with changed power of the laser.
– Erosion products are not settled over the processed surface, and their removal rate may be regulated by pressure adjustment.
– The interference with the station does not cause thermal stress or changes in the structure of the processed object.

## 7. CONCLUSION

Significant elements of the device are presented, including working nozzles and the method of their supply through the laser coupling device, and coupling heads. Other components are a result of conventional construction works.
The station, results and possible experimental options are of interest for researchers working in the fields of medicine, veterinary medicine, cosmetology and biology.
Conclusions for the future are**:** optimisation of the head structure, following a previous optimisation/re-calculation of beam paths, selection of nozzles that could be easily adapted to current needs, construction of a manipulator, equipment of the station with a software-controlled XY table. The operations were a subject of seminars held in COBRABID, Warsaw Technical University (Mechatronics Dept.) and were presented on conferences [3, 4].

## LITERATURE


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