ADCP-S IN THE DISCHARGE MEASUREMENT IN HUNGARY

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Abstract: The ADCP-s represent a new discharge-measuring technology in Hungary. Before integrating the ADCP among the standardized tools of the hydrography, there was a need to investigate the reliability of the results of the ADCP, moreover the differences between the ADCP and the traditional methods and the limits of the application. This paper is a summary of the experiences and the conclusions deriving from the practical measurements and special measuring programs.
Keywords: ADCP, Doppler shift, discharge measurement.

DIE ADCP IN ABFLUβMESSUNG IN UNGARN

Zusammenfassung: Die ADCP vertreten in Ungarn eine neue Messungstechnologie. Bevor wir die ADCP in die standardmäβigen hydrographischen Geräte eingeführt hatten, mussten wir überprüfen, wie zuverlässig die Ergebnisse von ADCP sind, was für Unterschiede zwischen diesen neuen und den tradizionellen Methoden sind und welche die Grenzen der Anwendung sind. Diese Arbeit fasst die aus der praktischen Anwendung des Gerätes und den speziellen Messunsprogrammen stammenden Erfahrungen und die Schluβ-folgerungen zusammen.
Schlüsselworte: ADCP, Doppler-Effekt, Abfluβmessung

1. Introduction

Whole territory of Hungary belongs to the catchment of the Danube. As the country lies at the bottom of the basin, it is exposed to the floods of the Danube and its big tributaries, as well as the water management activity of the upstream countries.

The observation of the water regime on the big rivers had been started as early as the beginning of the 18-th century. Somewhat later also the regular measurement of the discharge started. These works even now belong to the main duties of the hydrographical service of Hungary. Nowadays the discarge is measured 5 times a year at many stations on the big rivers, moreover extraordinary measurements are done in case of extreme situations. Completing discharge measurements with traditional tools (current meter) is rather expensive and time-consuming work (it takes e.g. half a working day and 500-600 Euro pro section for the Danube). This is why we took particular interest in the measuring technology built on *ADCP* (Acustic Doppler Current Profiler) tools, hoping that aplying these instruments we can meet our obligations much more efficiently and economically.

An ADCP system determines the discharge on the basis of the $Q = v.A$ equation, where A is the crossectional area of a river section and v is the mean velocity of the water for A.

The ADCP beams acustic signal into the water and utilizes the echo sound reflected by the suspended sediment and other particulars in the water. It has three or four *transducers* to produce the acustic beams and to receive the echo. As a consequence of the *Doppler shift*, the reflected signal differs from the emitted one and this difference is effected by the velocity of the water. Analysing this change the ADCP system is able to calculate the water velocity. Moreover the ADCP is able to give the velocity values for the whole vertical, deviding it in several *depth cells*. Sending and receiving the signal once is called a *ping*.

The measurement is performed crossing continuously the river, while the instrument makes a ping in every second or so. Using also the Doppler effect the ADCP tracks the bottom at the same time and calculates the speed of the moving boat. On the base of these information and measuring the water depth also the crossectional area is determined, along the way of the boat. After all the discharge is calculated as

$$Q = \sum_i v_i \cdot A_i$$

where $\boldsymbol{A_i}$ is a little part-area and $\boldsymbol{v_i}$ is the mean velocity of the water flowing through $\boldsymbol{A_i}$. More accurate result can be produced doing more transects and averaging the results. A complete measurement with typically four transects takes about 30 minutes on the Danube.

In 2001 the Lower Danube Water Authority (ADUVIZIG), first in Hungary, purchased an ADCP from the RD Instruments (RDI, San Diego, USA). The *ADCP Workhorse Rio Grande 600 kHz* had been choosen considering the typical current conditions (water depth, velocity) on the Danube (Figures 1-2.). Somewhat later four other institutes started to work with ADCP-s.

As the ADCP represented a new measuring technology in Hungary, naturally the following questions cropped up:

- how accurate are the results measured by the ADCP?
- what kind of measuring conditions are needed by the ADCP?
- what is the range of the application?

The upper questions are not described by this approach in the manuals of the ADCP-s, therefore we tried to find the answers in our practical experiences.

Figure 1. The ADCP Workhorse Rio Grande 600 kHz ADCP of the RD Instruments, mounting position.

We planned to do simultaneous measurements together with the regular, current meter method. Over our original plans there were also two big floods in 2002 on the Danube, allowing to test the ADCP in very extreme contitions.

This paper summarises our experiences in the two recent years. Though our aim was to become acquainted with the capabilities of an ADCP system, it was not an official test and we do not intend to qualify some actual instrument.

2. ADCP measurements of ADUVIZIG, comparison with the current meter results

2.1 Regular measurements

Normally the discharge is measured 5 times a year at 4 sections of the Danube along the reach that the ADUVIZIG is responsible for. Traditionally rotating current meters (OTT or SEBA type) with a diameter of 125 mm and with a pitch of 250 mm are used for the velocity measurement. According to our earlier experiences these tools are reliable and the results supplied by these traditional measurements are considered to be correct.

In the two recent years we managed to compile about 40 simultaneous measurements on the Danube in normal hydrological situation. That is, the flow in the river was low or near to the meanflow (though the flow was not always entirely permanent). The river bed was stable (gravel and/or sand) and the depths was enough to meet the requirements of the ADCP. There were done 4 or more transects by the ADCP every time. We worked in the same river section as the current meter. The discharges measured were in the range of 930-3800 m^3s^{-1}. The mean water velocity was 0.7-1.2 m/s.

The parameters of the comparison

The *discharge, **Q*** is the most important parameter of the comparison. Also the *cross-sectional area, **A*** can be compared but only if the two kind of measurements are done at the same river section.

The straight transect of the boat is not required when the discharge is measured by ADCP. Therefore the sequence of the subsequent verticals along the way are not in the same plane but they form a curving surface of these verticals. At processing the ADCP data by the *WinRiver* software of the RDI there are three alternatives to calculate the cross-sectional area. It can be calculated as:

- the cross-sectional area perpendicular to the main flow,
- the cross-sectional area perpendicular to a given project direction,
- the cross-sectional area, parallel with the mean crossing direction.

We used the first of the above tree for the comparison.

The *mean velocity, **v*** of the water is a derived value for both methods (*v=Q/A*) so it is of no importance.

When the two kind of measurements are performed in the same section and the distances to the banks are measured precisely, the *width* of the section can also be used for checking.

Figure 2. The ADCP Workhorse Rio Grande 600 kHz ADCP in measuring position.

Results

Our first observation was that the own results of the ADCP (the results of the more transects) were very close to each other. Usually the differences remained below 2 percent (+/- 1 percent), and only exceptionally exceeded 4 percent (+/- 2 percent).

Comparing the results of the current meter and that of the ADCP we found little higher differences of about 4-5 percent. Analysing these results we found that the measured velocities were nearly the same and the differences derived from the depth measurements. We did further investigations for the depth with several tools (echo sounder, ADCP, sounding rod, cable+weight). But in fact these investigations proved only that the natural conditions (e.g. the river bed of the Danube) were not suitable to answer this question in the range of 2-3 percent of the depth. That is, if this difference approves to be significant in future, some more accurate comparisons will be needed.

2.2. Flood measurements

During the floods that happened in March and in August 2002, our ADCP-team worked at 6 stations along a 120 km long strech of the Danube. An other team did daily measurements with current meter on a big ship at one of the stations. From time to time we worked together to compare the results. The discharges measured were in the range of 4100-8100 m^3s^{-1}. The mean water velocity was 0.9-1.6 m/s.

Already in March we found that the traditional method produced higher discharges than the ADCP. The difference was about 7-8 percent. In order to find the cause we had fixed the boat with the ADCP to the big ship, and did comparing measurements at the same verticals. Suprising we noticed that the screen of the computer that was used to follow the work of the ADCP, showed the continuous „moving” of the fixed boat agaist the water. We have found out that this phenomenon derived from the movement of the bottom sediment. Normally the ADCP calculates its own position and movement compared to the bottom. If there is a moving bed-load at the bottom, it results an error of the calculated boat velocity and also in the water velocity. At some verticals this virtual velocity reached 0.2 $m \cdot s^{-1}$.

The handbook of the ADCP takes the attention to the problem of the moving bottom. They recommend to start the work with a *test run* every time the measurement is done at an unknown place or if extremely high water velocities can be expected. The test run means that the boat starts its way at a marked point, makes a circle and returns to the starting point. If the movement of the bottom arises than the software of the ADCP draws the closing point to the upstream of the starting one on the screen.

After learning the aboves, durig the flood in August 2000, we started all measurements with a test run. Moreover we did these runs doing complete crossing of the river (without stopping the measurement on the other side). We have found that there are considerable differences among the measured sections, that is, the wandering of the bed-load is not steady along the river. At some stations it is negligible, but at other places it is high and influences the results significantly (Figure 3.).

The manufacturer of the ADCP suggests using of a GPS system to solve the problem. In this case the bed tracking is replaced by the GPS. This solution needs rather precise (and expensive) GPS system (with the accuracy of 1-2 cm). The ADCP system of the RDI is prepared to receive GPS data. In our testing measurement the ADCP worked without problems with the GPS (LEICA SR 530).

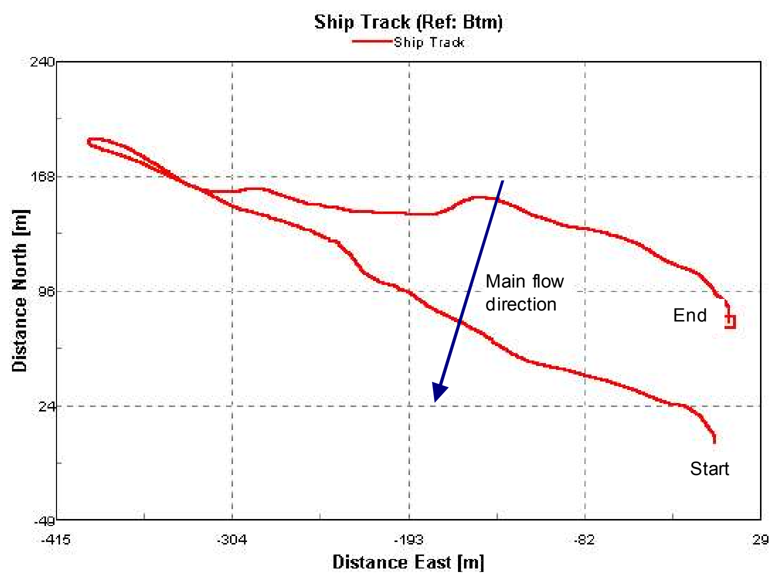

Figure 3. The route of a pre-run recorded by the ADCP (21. 08. 2002. Dunaszekcső, Hungary) While the measuring boat returned actually to the starting point, the ADCP „arrived" to another point at about 64 m upstream the start place. It indicates the average shift of the bottom of the same distance.

Theoretically, using the results of the test-run, some correction of a flood-result can be practicable.

After finishing the test-run the software of the ADCP supplies the virtual ΔL distance between the starting and closing points and also the T time of the test-run. By $\Delta v=\Delta L/T$ the average velocity of the moving bed-load can be calculated. Using the discharge Q and cross-sectional A results of the ADCP a $v_m=Q/A$ measured mean velocity can be calculated. Corrected this by Δv, that is $v_c=v_m\pm\Delta v$ a corrected value for the discharge, that is $Q_c=v_c*A$ can be calculated.

This method presumes a constant speed of the boat (this usually can not be performed in the reality). But we may split the route into short sections and weight them by the real momentary speed of the boat. An adequate software would be needed to do this. The WinRiver does not support this kind of correction.

During the floods we had another strange observation. At some stations there were many pings where the data ensembles were lost. We found that this phenomena was more or less proportional with the moving of the bottom. We supposed that there was a strong turbulence near the bottom, as a consequence of the high speed. The matearial of the bed swirled up making a cloud and the ADCP was not able to track the bottom. We noticed the same phenomena also downstream of the piers of bridges. But, as we observed, some lost ensembles did not significantly influence the results.

Foreshores

During the floods we tried to do our measurements mainly in the river sections where the flow on the foreshores was negligible. We chose typically ferry-sections where we can measure from slip to slip. In some cases also the road to the ferry was inundated, and there was a flow through above the road. We attempted the measurement where the depth reached 1 m. We used a special workig mode (M5) of the WorkHorse ADCP and we could qualify the results as rough estimation.

At the town of Baja we had a very special situation. The foreshore on the right side of the Danube is about 10 km wide. (It is a flood-plane forest and belongs to the Danube-Dráva National Park.) The foreshore is intersected by a main road and the water can only flow through four bridges. We made an attempt to measure the biggest one (length 160 m, depth 2.5-3.5 m). The measured section normally is dry and covered by bushes and other vegetation. We found that this vegetation disturbed the bottom tracking of the ADCP very much and it caused many lost data ensembles. At last the measurement was performed, but we considered the result again as rough estimation. We could check, that the discharge is underestimated with about 10-15 percent. The consequence is that reliable result can only be expected on foreshores, if the section to be measured is kept clean of vegetation.

3. Comparing measurements with more ADCP-s

Nowadays there are 5 working ADCP-s in practice in Hungary. In order to share the experiences and to prepare recommendations for the water administration there were two meetings organized recently for ADCP users. The main object of these meetings was to compare the measuring tools and technology. All teams worked according to their skills and usual practice. The first meeting was carried out on the Danube at Baja station. The results are summarised in Table 1.

Table 1.

Comparing ADCP measurements 1.

Station: Danube - Baja

Date: 23. 09. 2003.

Measuring team	Mean time	Discharge	Area	Mean velocity	Width	Mode	Cell size	No. of transects	ADCP type
		[$m^3.s^{-1}$]	[m^2]	[m/s]	[m]		[cm]		
ADUVIZIG, Baja	11:36	**1308**	1930	0,68	414	M1	50	4	RDI WorkHorse 600 kHz
ADUVIZIG, Baja	13:45	**1296**	1946	0,67	412	M12	10	3	-„-
FETIVIZIG, Nyíregyhára	11:04	**1339**	1940	0,69	417	M5	40	4	-„-
DÉDUVIZIG, Pécs	11:16	**1291**	1918	0,67	418	M1	25	5	RDI WorkHorse 1200 kHz
VITUKI, Budapest	13:20	**1256**					50	6	RDI BB 1200 kHz
ÉDUVIZIG, Győr		**1301**						6	SONTEK ADP 1500 kHz
EJF-MF Baja		**1310**	1860	0,70	413				(Current meter)

The other meeting was organized in Budapest with the same participants. The Danube was measured downstream of an island (Szentendre island) and also the side branches were measured. The results are summarised in Table 2. Concerning these results, we were basically satisfied (the maximum differences are about 5-6 percent), though in some cases these differences appeared to be significant between the several instruments, therefore they need further investigation.

4. Summary

Our experiences with the ADCP system prove that this device works reliably and provides correct results, when the measuring conditions are adequate. For *good river bed* the accuracy of the ADCP can be kept below 2-3 percent. The „good river bed" means that the bottom is solid and stabil, the water is deeper as 2 m - even near the banks - and it is possible to approach the banks as near as 6-8 m. In Hungary these requirements can be met on the big rivers.

Large part of Hungary is plain where the bed of the slow rivers and channels is often silty and covered by reed-grass. Though there are special working modes for the low velocity, these conditions influence the accuracy of the ADCP-s unfavourably. In our measurements, we completed on these channels, we noticed higher differences among the results of the ADCP transects and also between the ADCP and current meter results. (Naturally, the current meter results are also influenced by the poor measuring conditions). Regarding the ADCP values, in the range of the discharge below 10 $m^3 \cdot s^{-1}$, with very low velocity we have found the maximum differences typically up to 15-20 percent. The accuracy of the measurement can be improved by doing more transects and calculating the average. The lowest value we have ever measured by ADCP was about 3 $m^3 \cdot s^{-1}$, that we accepted as rough estimation.

Table 2.

Comparing ADCP measurements 2.

Station: Danube - Budapest

Date: 07. 11. 2003.

Measuring team	Mean time	Discharge	Area	Mean velocity	Width	Mode	Cell size	No. of transects	ADCP type
		[m^3.s^{-1}]	[m^2]	[m/s]	[m]		[cm]		
Section: main river downstream Szentendre island									
ADUVIZIG	10:23	**1348**	1560	0.86	520	M1	50	4	RDI WorkHorse 600 kHz
- „ -	10:57	**1381**	1567	0.88	510	M12	10	2	- „ -
FETIVIZIG	11:05	**1385**	1611	0.86	522	M1	20	4	- „ -
DÉDUVIZIG	10:58	**1309**	1505	0.88	520	M1	25	4	RDI WorkHorse 1200 kHz
VITUKI	10:55	**1336**						4	RDI BB 1200 kHz
ÉDUVIZIG		**1314**						4	SONTEK ADP 1500 kHz
KVVIZIG	11:00	**1320**	1560	0.85	360				(Current meter)
Section: side branch 1 (Vác)									
ADUVIZIG	11:18	**1012**	1386	0.73	375	M12	20	4	RDI WorkHorse 600 kHz
- „ -	11:36	**1007**	1386	0.73	378	M1	50	2	- „ -
FETIVIZIG	12:06	**1029**	1406	0.73	371	M1	10	4	- „ -
DÉDUVIZIG	11:58	**977**	1349	0,72	372	M1	25	4	RDI WorkHorse 1200 kHz
VITUKI	11:30	**988**						4	RDI BB 1200 kHz
ÉDUVIZIG		**979**						6	SONTEK ADP 1500 kHz
Section: side branch 2 (Szentendre)									
ADUVIZIG	11:53	**340**	479	0.71	166	M1	50	2	RDI WorkHorse 600 kHz
- „ -	12:04	**352**	479	0.74	163	M12	20	4	- „ -
- „ -	12:13	**349**	477	0.73	164	M8	20	4	- „ -
FETIVIZIG	11:42	**352**	529	0,67	178	M1	10	4	- „ -
DÉDUVIZIG	11:34	**331**	494	0,67	171	M1	25	4	RDI WorkHorse 1200 kHz
VITUKI	11:50	**335**						4	RDI BB 1200 kHz
ÉDUVIZIG		**344**						4	SONTEK ADP 1500 kHz

The problem of the *moving river bed* has been described above. At present the only correct solution for this problem is to apply a suitable GPS system. Nowadays the cost of an adequate GPS exceeds that of the ADCP, but probably the trend of costs will be decrease in the future.

Traditionally, the *suspended sediment* is measured together with the discharge in Hungary. The old method means to gather water samples in many points of the section and to analyse them by laboratory work. This is a rather time-consuming and expensive process. Now, using an ADCP, it is a special problem, how we can make the two kind of measurements meet.

As the ADCP utilises the echo sound reflected from the suspended materials, logically the idea arises that this information should be also used to calculate the suspended sediment. The DRL Software Ltd. (UK) has developed a software named *SediView* that is able to utilise the data gathered by the RDI-ADCP-s. The SediView needs a rather complicated calibration process. Recently this application has been purchased by the ADUVIZIG. At present we are working on starting it up.

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Our above statements concern first of all the *RDI ADCP Workhorse Rio Grande 600 kHz* we have got direct experiences with.

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ADCP-s in the Discharge Measurement in Hungary

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Abstract

The *ADCP*-s represent a new discharge-measuring technology in Hungary (ADCP = Acustic Doppler Current Profiler). Before integrating the ADCP among the standardized tools of the hydrography, there was a need to investigate the reliability of the results of the ADCP, moreover the differences between the ADCP and the traditional methods and the limits of the application.

The first ADCP was put in use in 2002, by the Lower Danube Water Authority (ADUVIZIG) in Hungary. It was an *ADCP Workhorse Rio Grande 600 kH*, produced by the RD Instruments (RDI, San Diego, USA). Somewhat later four other institutes started to work with ADCP-s.

In the two recent years more hundred discharge measurements were done by ADCP-s, and many of them were done parallel with current meter method. These measurements cover normal and extreme flow situations, including two extreme floods in 2002 and an extreme low flow in 2003. We tested the ADCP both in good and in poor measuring conditions.

Our experiences with the ADCP system for normal flow situation prove that this device works reliably and provides correct results, when the measuring conditions are adequate. For *good river bed* the accuracy of the ADCP can be kept below 2-3 percent. The „good river bed" means that the bottom is solid and stabil, the water is deeper as 2 m - even near the banks - and it is possible to approach the banks as near as 6-8 m. In Hungary these requirements can be met on the big rivers.

During floods we found that the *moving bed effect* can significantly bias the results. The „moving bed" means the movement of the bed-load at the bottom. As the ADCP basically uses the bottom tracking as a positioning reference system, the velocity results are biased proportionally with the speed of the moving bed-load. The correct solution for this problem is to apply a suitable GPS system instead of bottom tracking.

When it is also needed to work on *foreshores*, inundated usually only during floods, reliable result can only be expected, if the section to be measured is kept clean of vegetation.

During low water periods it can happen, on the Danube also, that it is difficult to meet the basic requirements of the ADCP. In these situations we had good results with the latest measuring modes improved by the RDI for shallow water.

Large part of Hungary is plain where the bed of the slow rivers and channels is often silty and covered by reed-grass. Though the ADCP has got special working modes for the low velocity, these conditions influence the accuracy of the ADCP-s unfavourably. In our measurements, we completed on these channels, we noticed higher differences among the results of the ADCP transects and also between the ADCP and current meter results. (Naturally, the current meter results are also influenced by the poor measuring conditions). Regarding the ADCP values, in the range of the discharge below 10 $m^3 s^{-1}$, with very low velocity we have found the maximum differences typically up to 15-20 percent. The accuracy of the measurement can be improved by doing more transects and calculating the average. The lowest value we have ever measured by ADCP was about 3 $m^3 s^{-1}$, that was accepted as rough estimation.