MODERN ELECTRIC TRACTION OF ŠKODA PLZEŇ VEHICLES

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Abstract: Výroba elektrických hromadných vozidel ŠKODA Plzeň – Transportroniky vyvíjí a vyrába elektrické trakční polohy na tržišti technologií, tím se dodávka dopravního zařízení v ČR až o zahradní na její širší činnosti podpoří dovozům a inženýrského a doktorandského studia v Zlíně.

Summary: The electric traction vehicle producing plant ŠKODA Plzeň – Transport has been producing many types of electric traction vehicles (ETV) during last about 80 years: for railways, coalmines and city public transport. These vehicles are in service from the Pacific Ocean coast in Russia over Asia, Europe to the Pacific Ocean west coast in USA.

1. INTRODUCTION

Today's producing plant ŠKODA Plzeň Transportation had been producing many thousands of electric traction vehicles (ETV) during last about 80 years: for railways, coalmines and city public transport. These vehicles are in service from the Pacific Ocean coast in Russia over Asia, Europe to the Pacific Ocean west coast in USA. The successful ETV production is determined by the ŠKODA-staff great experience and by application of innovative technologies. It must be said that many MSc. and PhD. graduates of today's University of Zlín had been taking part in the modern traction drives SKODA development. The electric traction drives SKODA development can be divided into 3 categories shown in Table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Power control</th>
<th>Power control principle by DC supply systems</th>
<th>Power control principle by AC supply systems</th>
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<tbody>
<tr>
<td>1st generation</td>
<td>Contact, DC TM</td>
<td>Resistance voltage control + field weakening</td>
<td>Transformer voltage control + diode inverter + resistance field weakening</td>
</tr>
<tr>
<td>2nd generation</td>
<td>Inverter, DC TM</td>
<td>Thyristor-chopper control + field weakening</td>
<td>Thyristor-controlled rectifier + field weakening</td>
</tr>
<tr>
<td>3rd generation</td>
<td>Inverter, AC TM</td>
<td>GTO/T/GTO/DC/LS-VVF</td>
<td>GTO/T/GTO/DC/LS-VVF inverter control and field weakening</td>
</tr>
</tbody>
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In this contribution, the development of the 3rd generation ŠKODA electric traction drives and vehicles with asynchronous traction motors will be shortly described.

2. ELECTRIC LOCOMOTIVES 3rd GENERATION ŠKODA

2.1 Electric 3 kV dc locomotive Škoda 85 E0

Two prototypes of electric locomotive (EL) 85 E0 were designed and built in 80's years: one of them with gearless asynchronous traction motor (ATM), see Fig. 2, the second one with gearbox and high revolutions ATM.

Main EL data:

Axle arrangement Bo'Bo' EL mass 84 t
Maximum speed 120/160 km/h Continuous traction power 3000/4000 kW

Resistance EDB max. braking output 3170 kW

Main 3-phases ATM data:

Continuous power 750/1000 kW
1-phase nominal voltage 1200 V
Continuous revolutions 317/443 r/min
Max. revolutions 417/736 r/min
Fully spring-mounted

2.2 Electric 3 kV DC shunting/universal ŠKODA 90 E

The 90 EL, Fig. 3, was designed for shunting operations and as a light universal locomotive for railways. 4 pieces of the 90 E were built and sold to Severočeská uhlířská (Northern Bohemia Coal Co.) till 1996.

Fig. 1 Gearless 85 E0: 1 - stator, 2 - rotor, 3 - coupling, 4 - driven axle

The traction circuit of 85 E0 designed in 80's years was set up from:

- input voltage control thyristor choppers,
- DC intermediate circuit,
- DC/AC 3-phases current inverters with frequency control,
- four squirrel-cage 3-phases ATM.

Always two asynchronous traction motors (ATM) in one bogie were fed from one scalar controlled DC/AC inverter. The inverter control was reconstructed on the vector control later.

Fig. 2 The first "asynchronous" ŠKODA locomotive 85 E0 traction circuit

This Bo'Bo' EL was the first ŠKODA "asynchronous" locomotive with an own ŠKODA microprocessor traction drive control and with GTO-thyristors DC/AC inverter. Because of lower allowed reverse GTO-thyristors voltage had to be used an input chopper decreasing the up to 3600 V input supply voltage.

The traction circuit consists of the input chopper decreasing continuously the voltage for the intermediate DC circuit 2400 V and two Y/VVF GTO-inverters supplying each of them to two in parallel connected 400 kW, 3-phases squirrel-cage asynchronous traction motors.

Fig. 3 The Bo'Bo', 1600 kW nominal output EL 90 E
MODERN ELEKTRICKÁ TRAKCIA VOZIDEL ŠKODA PLZEŇ
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Summary The electric traction vehicle producing plant ŠKODA Plzeň – Transportation plays a significant role in the future of electric vehicles. Electric vehicles deliver the most objective data about their performance. Students of the University of Žilina are involved in the development of the ŠKODA vehicle.

1. INTRODUCTION

Today’s producing plant ŠKODA Plzeň Transportation had been producing many thousands electric traction vehicles (ETV) during last about 80 years for railways, coalmines and city public transport. These vehicles are in service from the Pacific Ocean coast in Russia over Asia, Europe to the Pacific Ocean west coast in USA.

Table 1 SKODA electric locomotive drives classification

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Resistance EDB max. braking output 3170 kW

Main 3-phases ATM data:

- Continuous power 750/1000 kW
- 1-phase nominal voltage 1200 V
- Continuous revolutions 317/443 r/min
- Max. revolutions 417/736 r/min
- Fully spring-mounted

Both the 85 E0 are in service on ČD (Czech Railways) but the series production of them had not started because the technology development, mostly in the inverter control technology and IGBT characteristics improving enabled to design the modern voltage inverters with both voltage and frequency (VVF = Variable Voltage Variable Frequency) control.

2.2 Electric 3 kV DC shunting/universal ŠKODA 90 E

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2.3 Electric equipment of the 3 kV DC emu series 471 ČD

This ČD unique automation system had been developed by VÚZ Praha and digitalised by AZD Praha by PhD. study graduates of Dpt. of Electric Traction University of Zilina Dr. Ing. A. Lieskovský and Dr. Ing. I. Mysliveč.

Fig. 4 A train consisting of more 471 EMUs

Characteristics of the 471 EMU were described in detail in [1]. The unit can consist of following vehicles:
- 471 series driving trailer,
- 971 series steering coach;
- 071 series intermediate passenger coach.

Main vehicles characteristics are given in Table 2.

Table 2. Vehicles technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track gauge</td>
<td>1455 mm</td>
</tr>
<tr>
<td>Traction supply system</td>
<td>3 kV DC</td>
</tr>
<tr>
<td>Maximum speed (varients)</td>
<td>140 (166, 120) km/h</td>
</tr>
<tr>
<td>471 rated output</td>
<td>2 000 kW</td>
</tr>
<tr>
<td>EDWR output</td>
<td>1 700(2 000) kW</td>
</tr>
<tr>
<td>Maximum traction effort</td>
<td>180 kN</td>
</tr>
<tr>
<td>Maximum braking effort</td>
<td>145 kN</td>
</tr>
<tr>
<td>Axle arrangement</td>
<td>Bo Bo' 2'/2'/2'/2'</td>
</tr>
<tr>
<td>Total vehicle length (by all)</td>
<td>26 400 mm</td>
</tr>
<tr>
<td>Total width (by all)</td>
<td>2 820 mm</td>
</tr>
<tr>
<td>Total height over rail head</td>
<td>46 535 mm</td>
</tr>
<tr>
<td>Maximum axle load mass</td>
<td>&lt; 20 t</td>
</tr>
</tbody>
</table>

Fig. 5 The microprocessor control and diagnostic system of EMU-471 ČD

The traction circuit described more in detail in [1] consists of:
- 3 kV DC supply via the main circuit breaker and the input filter inductivity,
- two intermediate DC 1.5 kV in series connected voltage circuits,
- four water-cooled inverter IGBT-VVVF 1.5 kV DCx x (0 - 1130 V, 0 - 200 Hz),
- four squirrel-cage 3-phases asynchronous traction motors with 2 stator windings - ever of them - from two different VVVF inverters with 1.5 kV input voltage. The motors have 4 x 500 kW output power. Traction circuit is in Fig. 6.

Every of vehicles have its own maximally autonomous operation/diagnostics control provided by “central vehicle computer”, see Fig. 5. Only functions common for all vehicles in the train are controlled from “master” computer in the driver vehicle (471 or 971) via WTB connection. Other central vehicle computers work in “slave” regime in this case. A longer train can be set up from more EMU’s and centrally controlled by driver. Also the automatic train operation (ATO) is controlled from the “master” central vehicle computer in the driver’s driving trailer (471) or steering coach (971) securing required automatic train movement, automatic target braking (ATB) and energy consumption optimisation (ECO).

The double-deck passenger rooms are air-conditioned and divided to 1st and 2nd class compartments. The central vehicle computer informs passengers both by electronic panel and sound announcement.

Totally 15 three-vehicles EMU’s series 471 operate on suburban ČD routes today. Another 15 EMU’s are ordered and will be delivered till 2007.

2.4 3-systems express locomotive 109 E

The locomotive is intended to haul EC/IC and express train in Czech Republic, Slovakia, Germany, Austria, Poland and Hungary as well as for the transport on EU “corridors” electrified by 3 kV DC, 25 kV/50 Hz and 15 kV/16,7 Hz supply systems.

The primary traction transformer winding can be switched over both for 25 kV and 15 kV systems. By the 3 kV DC supply system, the secondary traction transformer windings are utilized like inductors of the locomotive input current filter. Four traction motors are asynchronous three-phases ones with two in double star connected stator windings. The rated output of the motor shafts is 4 x 1 600 kW. Locomotive both traction and auxiliary asynchronous drives are processor-controlled enabling the multiple control of coupled locomotives from one locomotive or steering vehicle stand.

Totally 20 locomotives 109 E were ordered by ČD. The locomotive electric equipment is under construction and ought to be tested mounted into the mechanical part one of 85 E0 locomotives during the year 2005.

Fig. 6 The 471 ČD traction circuit

Main 109E technical parameters
- Axle arrangement Bo' Bo'
- Max. speed 200 km/h
- Draw-hook continuous power 6 050 kW
- Speed at the continuous power 102 km/h
- Draw-hook traction effort by the continuous power 213 kN
- Max. draw-hook traction effort 274 kN
- Max. one traction motor phase

Gauge 1 435 mm
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acceleration current 647 A
EDB power at the wheel-rim:
regenerative brake 6 963 kW
resistor brake 4 700 kW
Max. EDB braking effort 226 kN
Vehicle length over buffers 18 000 mm
Diameter of (new) wheels 1 250 mm
Locomotive max. width 3 070 mm
Locomotive max. height above the top of rail 4 280 mm
Total mass 86 t (+3%, -1%)
Axle load 21.5 t
Bogie mass 15.8 t
Min. curve radius 120 m

3. TRAMWAYS ŠKODA

The rapidly decreasing orders of new electric locomotives after the social changes in the Middle Europe and Soviet Union made the plant ŠKODA to fetch a new production and trade branch. It was found in the production of modern trams with asynchronous traction drives for Czech cities and for the export, i.e. to the USA.

The first tramcar called ASTRA was originally equipped by firma ELIN traction drive with 3-phases asynchronous TM and air-cooled IGBT voltage VVVF inverters connected directly to 600/750 V DC supply voltage.

Maximum deceleration value (normal operation) 1.3 m/s²
Vehicle floor height over the rail top:
in lower part 350 mm
in taller parts 780 mm
Vehicle body length 20 990 mm
Vehicle mass – empty 24 200 kg ± 5%
Vehicle mass – fully occupied 39 740 kg
Passengers max. number 221
Traction output: rated/max. 4 x 90 kW/500 kW
Regenerative/张贴 resistance EDB output 750 kW
Emergency brake: 4 jaw type rail brake

Since 2000, trams ASTRA and following tram types are produced with own ŠKODA inverters IGBT-VVVF controlled by ŠKODA microprocessor system.

3.1 Three-sectional low-floor tram ŠKODA 03 T ASTRA

The three-sectional low-floor tramway car ŠKODA of the 03 T type can operate either in the “classic” city rail transport or in the rapid city/suburban transport. Thanks to the arrangement of cabling and the use of materials with the attestations of incombustibility, it is suitable also for use in tunnels. The middle low-floor part of the tramway car makes possible the comfortable entrance and exit for passengers with a reduced mobility. The disengaging platform makes easier the transportation of the passengers with a reduced mobility with a wheelchair or with a buggy.

Main vehicle data:
Axle arrangement Bo’Bo’
Max. speed in city/rapid transport operation 50/70 km/h
Maximum construction speed 75 km/h
Maximum service speed 70 km/h
Maximum acceleration value 1.5 m/s²
Emergency brake max. braking effort 4 x 70 kN up to ca 6 m/s² deceleration value.

3.2 Five-sectional low-floor tram ŠKODA 05 T – VEKTRA

Semi low-floor tramcar vehicle VEKTRA consists of five sectional car bodies mounted on three traction two-axle bogies. The vehicle was developed as a functional sample on basis of tram ŠKODA 03 T. Vehicle is driven by asynchronous traction motors powered by two traction inverters using IGBT SKILP modules. Vehicle is equipped by both transparent visual and acoustic microprocessor controlled info systems. Train is also equipped for easy transport of disabled passengers.

Tram VEKTRA has the axle arrangement B’Bo’/Bo’/B’. The not driven sections both by VEKTRA and ASTRA are hung up without bogies. At the moment, a VEKTRA variant for Prague city transport is prepared where 20 vehicles were ordered. Another 6 vehicles are built for Cagliari (Italy).
acceleration current 647 A
EDB power at the wheel-ring:
regenerative brake 6 963 kW
resistor brake 4 700 kW
Max. EDB braking effort 226 kN
Vehicle length over buffers 18 000 mm
Diameter of (new) wheels 1 250 mm
Locomotive max. width 3 070 mm
Locomotive max. height above the top of rail 4 280 mm
Total mass 86 t (+3%, -1%)  
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Vehicle body length 20 090 mm
Vehicle mass – empty 24 200 kg ± 5%
Vehicle mass – fully occupied 39 740 kg
Passengers max. number 221
Traction output: rated/max. 4 × 90 kW/500 kW
Regenerative/Resistance EDB output 750 kW
Emergency brake: 4 jaw type rail brake

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At the moment, a VEKTRA variant for Prague city transport is prepared where 20 vehicles were ordered. Another 6 vehicles are built for Cagliari (Italy).
higher level floor section 780 mm
Wheel diameter new/used 610/530 mm
Empty vehicle mass 28 800 kg
Normally loaded vehicle with a driver 39 060 kg
Continuous output 4 x 50 kW
Maximum acceleration output 645 kW
Maximum breaking output 960 kW

4. TROLLEYBUSES ŠKODA 24 Tr AND 25 Tr

The asynchronous drive with IGBT-VVVF inverter was used also by trolleybuses ŠKODA 24 Tr (solo vehicle) and 25 Tr (articulated two-sectional vehicle). Both the vehicles are maximally unified one to another and together with buses IRISBUS produced in co-operation KAROSA (CZ/RENAULT F) for CZ as well for the export. This minimized the needed spare parts number in city public transport corporations where both buses and trolleybuses operate.

<table>
<thead>
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<tbody>
<tr>
<td>Continuous motor power</td>
</tr>
<tr>
<td>Length/width/height</td>
</tr>
<tr>
<td>Length with collectors pulled down</td>
</tr>
<tr>
<td>Platform height of all doors</td>
</tr>
<tr>
<td>Outer turning circle diameter</td>
</tr>
<tr>
<td>Vehicle mass</td>
</tr>
<tr>
<td>Maximum vehicle speed</td>
</tr>
<tr>
<td>Seating passengers</td>
</tr>
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<td>Standing passengers</td>
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<table>
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<tr>
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<tr>
<td>Standing passengers</td>
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Main vehicle parameters
Wheelset arrangement Bo'Bo'
Maximum operation speed 70 km/h
Construction speed 75 km/h
Body length 20 130 mm
Floor level above the rail surface:
low-floor section 350 mm

The greatest part of the vehicle electric equipment is placed under the vehicle roof, i.e. traction IGBT-VVVF inverter, auxiliary drives inverter, vehicle battery charging inverter, vehicle room heating (and – optionally – air-conditioning) inverter, main switches and fuses and inverter control units. Vehicles have regenerative and resistance EDB and continuous electronic isolation diagnostics. Either the diesel-electric or traction battery auxiliary traction supply enabling to overcome a short route parts without trolley supply can be delivered optionally.

<table>
<thead>
<tr>
<th>Table 5 ŠKODA 25 Tr traction inverter main data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous rated output</td>
</tr>
<tr>
<td>Nominal DC supply voltage</td>
</tr>
<tr>
<td>Output AC voltage</td>
</tr>
<tr>
<td>1-phase output nominal/max. Current</td>
</tr>
<tr>
<td>Output frequency</td>
</tr>
<tr>
<td>Modulation frequency</td>
</tr>
<tr>
<td>Input capacitor capacitance</td>
</tr>
<tr>
<td>Nominal power losses by 50 Hz</td>
</tr>
</tbody>
</table>

Trolleybuses ŠKODA are delivered not only for Czech cities. Totally 150 vehicles were delivered to California, USA, in last years. Total 28 sets of electric equipment for „solo“ trolleybuses were delivered in 2004 and 32 sets for articulated trolleybuses are produced and tested for Boston, see Fig. 14.
The vehicles are completed in Boston in co-operation with the body producing firma NEOPLAN – USA.
higher level floor section 780 mm
Wheel diameter new/sworn 610/530 mm
Empty vehicle mass 28 800 kg
Normally loaded vehicle with a driver 39 060 kg
Continuous output 4 x 90 kW
Maximum acceleration output 645 kW
Maximum breaking output 960 kW

4. TROLLEYBUSES ŠKODA 24 Tr AND 25 Tr

The asynchronous drive with IGBT-VVVF inverter was used also by trolleybuses ŠKODA 24 Tr (solo vehicle) and 25 Tr (articulated two-sectional vehicle). Both the vehicles are maximally unified one to another and together with buses IRISBUS produced in co-operation KAROSA (CZ/RENAULT (F)) for CZ as well for the export. This minimized the needed spare parts number in city public transport corporations where both buses and trolleybuses operate.

Table 3 Trolleybus ŠKODA 24 Tr main characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous motor power</td>
<td>210 kW</td>
</tr>
<tr>
<td>Length/width/height</td>
<td>11 990 / 2 500 / 3 500 mm</td>
</tr>
<tr>
<td>Length with collectors pulled down</td>
<td>12 860 mm</td>
</tr>
<tr>
<td>Platform height of all doors</td>
<td>320 mm</td>
</tr>
<tr>
<td>Outer turning circle diameter</td>
<td>22 600 mm</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>11 500 kg</td>
</tr>
<tr>
<td>Maximum vehicle speed</td>
<td>65 km/h</td>
</tr>
<tr>
<td>Seating passengers</td>
<td>30 persons</td>
</tr>
<tr>
<td>Standing passengers</td>
<td>69 persons</td>
</tr>
</tbody>
</table>

Table 4 ŠKODA 25 Tr main characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous motor power</td>
<td>240 kW</td>
</tr>
<tr>
<td>Length/width/height</td>
<td>17 800 / 2 500 / 3 500 mm</td>
</tr>
<tr>
<td>Length with collectors pulled down</td>
<td>18 400 mm</td>
</tr>
<tr>
<td>Platform height of all doors</td>
<td>320 mm</td>
</tr>
<tr>
<td>Outer turning circle diameter</td>
<td>22 400 mm</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>17 700 kg</td>
</tr>
<tr>
<td>Maximum vehicle speed</td>
<td>65 km/h</td>
</tr>
<tr>
<td>Seating passengers</td>
<td>40 persons</td>
</tr>
<tr>
<td>Standing passengers</td>
<td>110 persons</td>
</tr>
</tbody>
</table>

The greatest part of the vehicle electric equipment is placed under the vehicle roof, i.e. traction IGBT-VVVF inverter, auxiliary drives inverter, vehicle battery charging inverter, vehicle room heating (and optionally - air conditioning) inverter, main switches and fuses and inverter control units. Vehicles have regenerative and resistance EDB and continuous electronic isolation diagnostics. Either the diesel-electric or traction battery auxiliary traction supply enabling to overcome a short route parts without trolley supply can be delivered optionally.

Table 5 ŠKODA 25 Tr traction inverter main data

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous rated output</td>
<td>225 kVA</td>
</tr>
<tr>
<td>Nominal DC supply voltage</td>
<td>600 V</td>
</tr>
<tr>
<td>Output AC voltage</td>
<td>3 x (0 + 420 V)</td>
</tr>
<tr>
<td>1-phase output nominal/max.</td>
<td>310/300 A</td>
</tr>
<tr>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>Output frequency</td>
<td>0 +150 Hz</td>
</tr>
<tr>
<td>Modulation frequency</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Input capacitor capacitance</td>
<td>12 mF</td>
</tr>
<tr>
<td>Nominal power losses by 50 Hz</td>
<td>3.9 kW</td>
</tr>
</tbody>
</table>

Main vehicle parameters
Wheel set arrangement Bo'Bo'
Maximum operation speed 70 km/h
Construction speed 75 km/h
Body length 20 130 mm
Floor level above the rail surface: low-floor section 350 mm

Trolleybuses ŠKODA are delivered not only for Czech cities. Totally 150 vehicles were delivered to California, USA, in last years. Total 28 sets of electric equipment for „solo“ trolleybuses were delivered in 2004 and 32 sets for articulated trolleybuses are produced and tested for Boston, see Fig. 14. The vehicles are completed in Boston in co-operation with the body producing firma NEOPLAN – USA.
REFERENCES


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- abstrakt (9 bodová normálne písno, tež v anglickom jazy- ku (Summary),
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- Full author's names (10-point bold font and aligned to the center),
- Address and affiliation (9-point italic font),
- Summary (9-point normal font) written in English,
- Paper text (10-point normal font, single line spacing) pre- pared in 3-column format (75 mm width, 10 mm space between columns) usually containing introduction, theore- tical part, experimental part, discussion, conclusion and references,
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7. Tables must be included in the text, numbered separately from figures (Tab. 1, Tab. 2, etc) with all necessary descrip- tion placed above them.
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