

'\QDPLF EHKDYLRXU RI SQHXPDWL
RSHQ ORRS FRQWUROOHG E\ SURSF

9DOHQWFRQBRFR&DUPHQ6DQFDQSQVWQDOWQLX

8QLYHUVLW\ 3ROLWHKQLFD RI %XFKDUHVW 3RZHU (QJLQHHUL
%XFKDUHVW 5RPDQLD

\$EVWUDFKM GHYHORSPhQW RI SURSRUWLRQDO DQG V
K\GUDXOLF FRQWURO WHFKQLTXH RIIHUHG WKH SUHPL
SQHXPDWLF FRQWURO WRR 'HVSLWH WKH GLVDGYDQ
DSSHUHG LQ WKH SQHXPDWLF V\ VWHPV DLU FRPSUH
FDXVHV WKH QHZ JHQHUDWLRQ RI SURSRUWLRQDO HT
KDYH D JRRG TXDOLW\ SQHXPDWLF FRQWURO V\ VWHP L
SDSHU LV WR GHPRQVUDWH E\ XVLQJ QXPHULFDO VL
SURSRUWLRQDO YDOYHV XVHG LQ SQHXPDWLF DFWXD
V\ VWHP G\QDPLF DW D UHDVQRDEOH FRVW DV DJDLQV
YDOYH DV LW XVXDOO\ XVHG LQ SQHXPDWLF DFWXDWRU

,QWURGXFWRQ

7KH SQHXPDWLF V\ VWHP GULYHV KDYH EHHQ ZLGHO\ XVH
WRROV LQGXVWULDO URERWV DXWRPRWLYH LQGXVWU
DXWRPDWLRQ HTXLSPHQW LV QHHGHG ,Q RXU GD\ V
LQGXVWULDO URERWV DUH XVLQJ SQHXPDWLF V\ VWHPV
RU LQ RSHQ ORRS DV SQHXPDWLF GULYHV > @

\$GYDQWDJHV RI SQHXPDWLF GULYHV WR EH OLJKW ZH
PDLQWDLQ WKH UREXVW GHVLJQ DQG RSHUDWLRQ DO
ZRUNLQJ WHPSHUDWXUHV WKH DLU PXVW QRW EH FRR
SUHIHUHG LQ PDQ\ DXWRPDWLF DSSOLFDWLRQV ,Q
PLFURHOHFWRUQLF WHFKQRORJ\ JRHV WR LPSURYH W
EHKDYLRXU RI WKH SQHXPDWLF V\ VWHPV GHVSLWH RI
GLIILFXOW WR FRQWURO 7KH JDV IORZ LWVHOI WKH JD
RI JDV UHVLVWDQFH WKH VPDOO YLVFRVLW\ FRHIILFLH
RI IDFWRUV ZKLFK KDYH D VWURQJ LQIOXHQFH LQ WKH
V\ VWHP @ >

3QHXPDWLF V\ VWHPV FRQYHUW WKH FRPSUHVVHG DLU
FDQ EH D XVHIXO PHFKDQLFDO ZRUN RU PRWLRQ 7KH
SQHXPDWLF DFWXDWRU SLVWRQ F\OLQGHU RU URWDU\

3QHXPDWLF DFWXDWRUV DUH GLUHFV GULYHQ V\ VWHP
RU WKH RXWSXW PRWRU VKDIW RI WKH URWDU\ PRWRU

&RUUHVSRRQ [GDQD XWKRUQDQFD#JPDLO FRP](#)

)UHTXHQWO\ WKH SQHXPDWLF DFWXDWRU LV FRQWUR
 ZKLFK FDQ EH D VHUYR YDOYH D SURSRUWLRQDO Y
 HOHFWURSQHXPDWLF YDOYHV DUH GHVLJQHG WR ZRUN Z
 VWDJH HOHFWURSQHXPDWLF FRQWURO YDOYH LV D GLU
 FRQWURO YDOYHV ZLWK WZR DQG WKHUHH VWDJHV DUH I
 WKH SUHVXUH RQ WKH RWKHU VWDJH 7KHVH DUH NQR
 7KH VHUYR YDOYHV SURYLGH D KLJKHU GHJUHH RI ORR
 SRVLWLRQLQJ \V\WHP IRU WKHLU@WLRQLQJ DFFXUD
 7KH JRDO RI WKH SDSHU LV WR VKRZ WKDW D SQHXP
 YDOYH DQG ZRUNLQJ LQ RSHQ ORRS FDQ KDYH D JRRG
 HOHFWULFDO VLJQDO ZDYHV 1XPHULFDO VLPXODWLRQ
 RIIHUHG E\ 6LPFHQWHU \$PHVLP ZLWK /06 ,PDJLQH /DE
 QXPHULFDO UHVXOWV DUH GLVFXVVG DQG ILQDO FRQF

3QHXPDWLF DFWXDWRU LQ RSHQ ORRS

6WDUWLQJ IURP WKH FODVVLFDO VWUXFWXUH RI D SQ
 FRQWUROHG E\ D VSRRO WISH GLUHFV VROHQRLG VSU
 FRQWURO YDOYH '&9 LW ZDV FKDQJH WKH '&9 ZLWK D
 D EXWWHUIO\ YDOYH XVHG LQ LQGXVWULDO DSSOLFDWLI
 7KH VFKHPH RI WKH SQHXPDWLF DFWXDWRU FRQWUR
 DGMXVWDEOH WKURWWOHV 7& 7& WR PRGL\ WKH SL
 DWWDFKHG RXWVLGH RI WKH F\OLQGHU WR SURYLGH D
 1RLVH GDPSHUV RU VLOHQFHUV DFFRUGLQJ WR ,62
 SUR[LPLW\ VHQRUV DQG WKH VLOHQFHUV DUH QRW ILJX

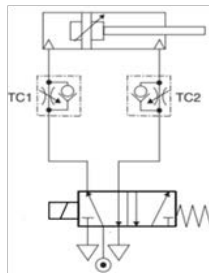
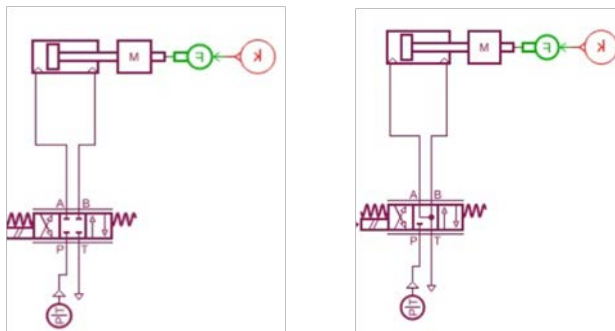


Fig. 1. 3QHXPDWLF DFWXDWRU ZLWK VROHQRLG '&9 DQG WKURWWOHV



D FORVHG FHQWHEU YDOYHV

Fig. 2. 3QHXPDWLF DFWXDWRU ZLWK SURSRUWLRQDO YDOYH \$PHVLP WKH PLUURU \V\PEROV IRU PDVV DQG FRQVWDQW IRUFH

,W LV NQRZQ WKDW WKH RSHQ ORRS SQHXPDWLF V\|VW
 DQG QRW DWWHQXDWH GLVWXUEDQFHV > @ 6R WKLW
 SDUDPHWHU YDULDWLRQV RI WKH LQSXWV 7KH SDUDPH
 V\|VWHP RXWSXWV
)RU WKLW UHDFRQ LW ZDV SURSRVHG D SQHXPDWLF D
 ZLWK IRXU ZD\|V DQG WКУHH SRVLWLRQV RI WKH VSRRO
 WZR FRQILJXUDWLRQV ZLWK FORVHG FHQWHU)LJXUH
 E

3QHXPDWLF DFWXDWRU SDUDPHWHUV DQG VL

7KH SQHXPDWLF DFWXDWRU SUHVHQWHG LQ ERWK FRQIL
 FKDUDFWHULVWLFV RI WKH SQHXPDWLF F\OLQGHU DQG
 ,PDJLQH /DEV 3QHXPDWLF OLEUDU\
 ✓ IRU WKH GRXEOH DFWLQJ SQHXPDWLF F\OLQGHU WK
 GLDPHWHU LV PP WKH OHQJWK RI WKH VWURNH LV
 FP WKH WRWDO PDVV EHLQJ PRYHG LV NJ WKH
 1V P WKH WHPSHUDWXUH LQ WKH LQSXW DQG RXWSX

✓ IRU WKH VSRRO W\|SH SURSRUWLRQDO YD\|VWHP
 QDWXUDO IUHTXHQF\ LV +] WKH YDOYH UDWHG FXU
 DQG WKH IORZ FRHILFLHQW LV
 7KH SQHXPDWLF V\|VWHP LV VXSSOLHG ZLWK FRPSUH
 SUHVXUH LQ WKH LQDFWLYH F\OLQGHU FKDPEHU LV E
 DV LQ WKH F\OLQGHU FKDPEHU 7KH SQHXPDWLF OLQH
 LV PP
 ,W ZDV FRQVLGHUHG WКУHH W\|SHV RI VLJQDO ZDYHV
 GHYLFH RI WKH SURSRUWLRQDO YDOYH ZLWK WKH FKDU

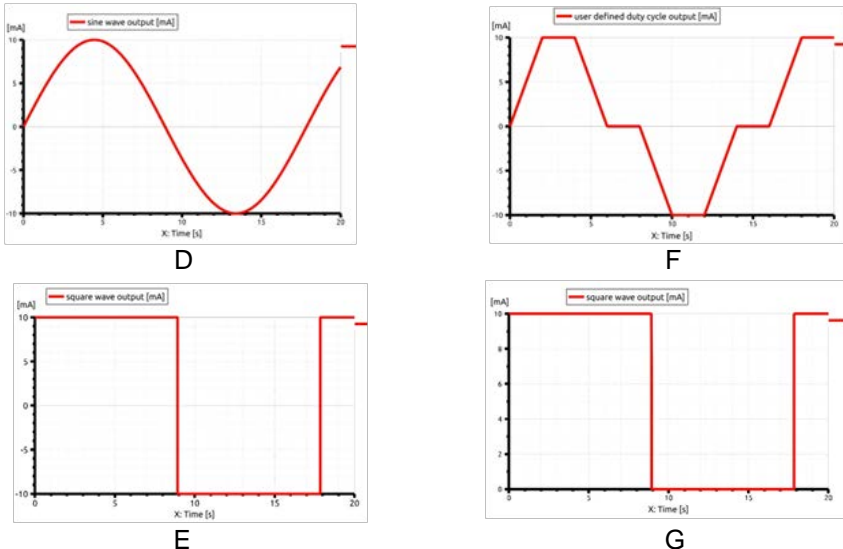


Fig. 3. 7КУHH W\|SHV RI VLJQDO FRPPDQG DSSOLHG WR WKH SURS
 ZDYH F WUDSH]RLGDO VLJQDO G GHPL VTXDUH ZDYH

7KH VLQH DQG VTXDUH ZDYH SURILOH VLJQDO FRPP
DPSOLWXGH DQG WKH ZDYH IUHTXHQF\ RI +] 7KH WU
F KDV WKH VDPH DPSOLWXGH G\PHI SHULRG RI V EXW ZLV
GHFHODWLRQ WLPH RI V HDFK DQG D WLPH RI V HD
ZDYH)LJXUH G KDV WKH DPSOLWXGH P\$ DQG V
GLDJUDP IRU D VROHQRLG '&9 KDV D WUDSH]RLGDO SUR
RI FRQWURO VLJQDO LQ WKLV VWXG\

1XPHULFDO VLPXODWLRQV RI SQHXPDWLF DFW

1XPHULFDO VLPXODWLRQV DUH SUHVHQWHG XVLQJ GD
VLPXODWLRQ PRGHO D FRQVWDQW UHVLVWDQW IRUFH F
7KH UHVLVWDQW IRUFH ZDV FDOFXODWHG UHJDUGLQJ W
\$UH SORWWHG WKH URG GLVSODFHPHQW DJDLQVW WL
HYROXWLRQ LQ F\OLQGHU FKPDEHUV IRU DOO WKH WK
DFWXDWRU VFKHPH LQ)LJXUH 7R D EHWWHU IROORZ
FDVHV DUH QDPHG DV

- ✓ 3\$ && 39 6,1: SQHXPDWLF DFWXDWRU ZLWK FORV
DQG VLQH ZDYH LQSXW UHVXOWV ZHUH SORWWHG
- ✓ 3\$ && 39 645: SQHXPDWLF DFWXDWRU ZLWK FORV
DQG VTXDUH ZDYH LQSXW UHVXOWV ZHUH SORW
- ✓ 3\$ && 39 75\$3 SQHXPDWLF DFWXDWRU ZLWK FOR
DQG WUDSH]RLGDO LQSXW UHVXOWV ZHUH SORW
- ✓ 3\$ %7 39 6,1: SQHXPDWLF DFWXDWRU ZLWK %7
ZDYH LQSXW UHVXOWV ZHUH SORWWHG LQ)LJXU
- ✓ 3\$ %7 39 645: SQHXPDWLF DFWXDWRU ZLWK %7
VTXDUH ZDYH LQSXW UHVXOWV ZHUH SORWWHG L
- ✓ 3\$ %7 39 75\$3 SQHXPDWLF DFWXDWRU ZLWK %7
WUDSH]RLGDO LQSXW UHVXOWV ZHUH SORWWHG

(DFK ILJXUH IURP WR KDV ILYH JUDSKLFDO UHSU
QXPHULFDO VLPXODWLRQ PRGHO E IRU URG GLVSODF
DJDLQVW WLPH G IRU URG DFFHOHUDWLRQ DJDLQVW
RI WKH ELJ DQG VPDOO F\OLQGHU FKPDEHUV

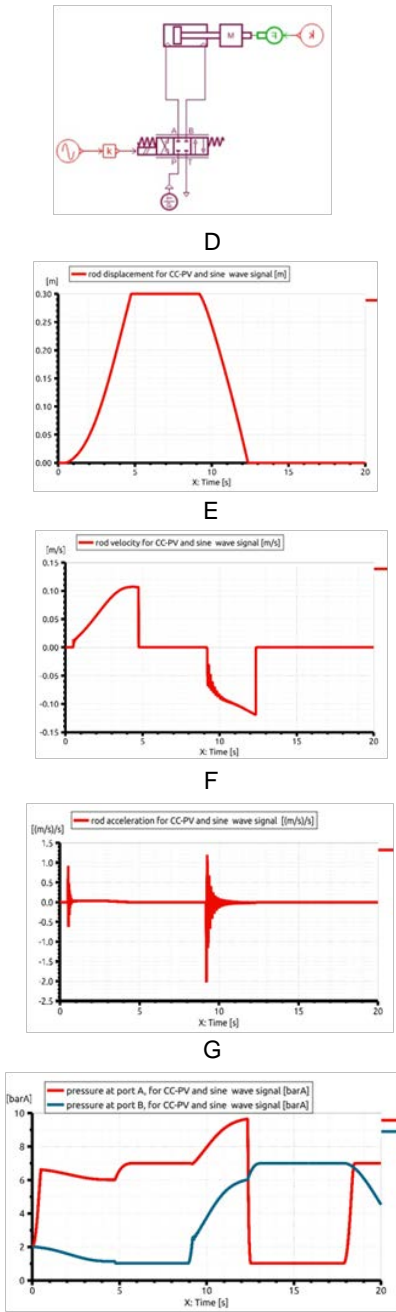
)URP WKH SORWWHG UHVXOWV VRPH JHQHUDO REVHUY
\$OO GLVSODFHPHQWV RI WKH URG KDYH WKUHH VSHF
WKH URG H[WHQGV DQG JHWV WKH VWURNH YDOXH RI
VWURNH ZLWK]HUR YHORFLWLHV WKH GHFUHDVH SDU
F\OLQGHU ,Q DOO VL[FDVHV DIWHU WKH H[SDQG GLVSO
GLVSODFHPHQW LV ORQJ 7KH URG LV QR PRUH PRYLQJ
WKH SURSRUWLRQDO YDOYH LV UHFHLYLQJ WKH HOHFWU

1XPHULFDO VLPXODWLRQV KLJKOLJKW WKH FRPSUHVV
REVHUYHG LQ WKH G\QDPLF UHVSQRVH RI WKH SQHXP
FRQWURO ZLWK VLQH ZDYH DQG WUDSH]RLGDO ZDYH FR
SQHXPDWLF DFWXDWRU ZLWK %7 YDOYH FRQWURO DQ
WLPH GHOD\ LV REVHUYHG WRR)LJ DQG)LJ

&RPSDUHG ZLWK WKHVH FDVHV WKH SQHXPDWLF DFW
QRW KDYH D GHOD\ WLPH LQ WKH PRYHPHQW QRW HYH
E\ SURSRUWLRQDO YDOYH ZLWK FORVH FHQWHU QRU ZK
DQG)LJXUH

7KH GHOD\ DUH EHWWHU KLJKOLJKWHG E\ WKH YHORE

\$OVR LW LV UHPDUNHG WKH DV\PPHWULF HYROXWLRQ
 D ORQJ WLPH RI PRYHPHQW WKDQ WKH UHWUDFW RI WKH
 DV\PPHWU\ LV QRW DYDLODEOH LQ WKH FDVH RI VTXDUH



4. 3\$ && 39 6, 1:

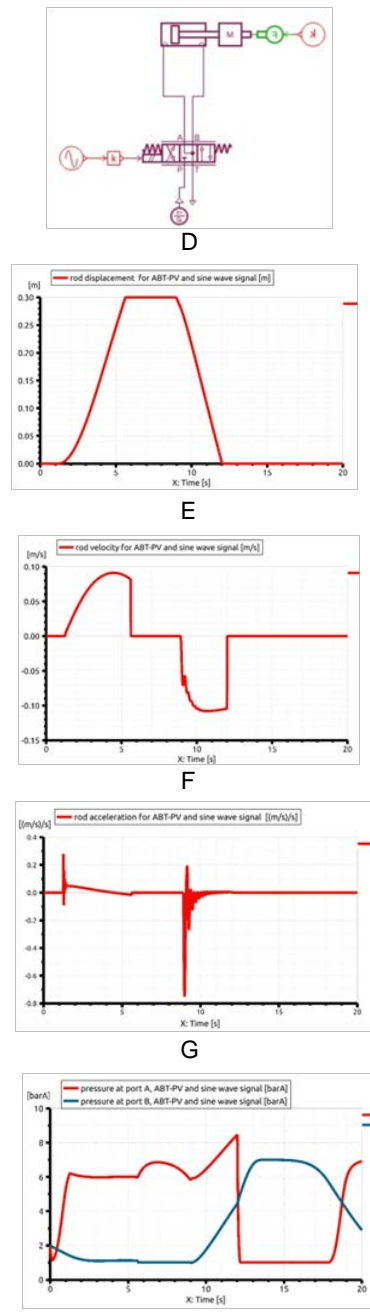


Fig.5 3\$ \$% 7 39 6, 1:

,Q ILJXUHV DQG LV REVHUYHG WKDW WKH WLPH GH
 FRQWURO YDOYH LV ORQJHU WKHQ LQ FDVH RI SQHXPV
 \$OVR LV REVHUYHG WKDW WKH YHORFLW\ HYROXWLRQ L

DQG WKH YHORFLWLHV DUH DOPRVW WKUHH WLPHV VPD
 VHH)LJ F DQG)LJ F 7KH DFFHOHUDWLRQ YDOXH
 YDOYH WKDQ WKH FORVH FHQWHU FRQWURO YDOYH

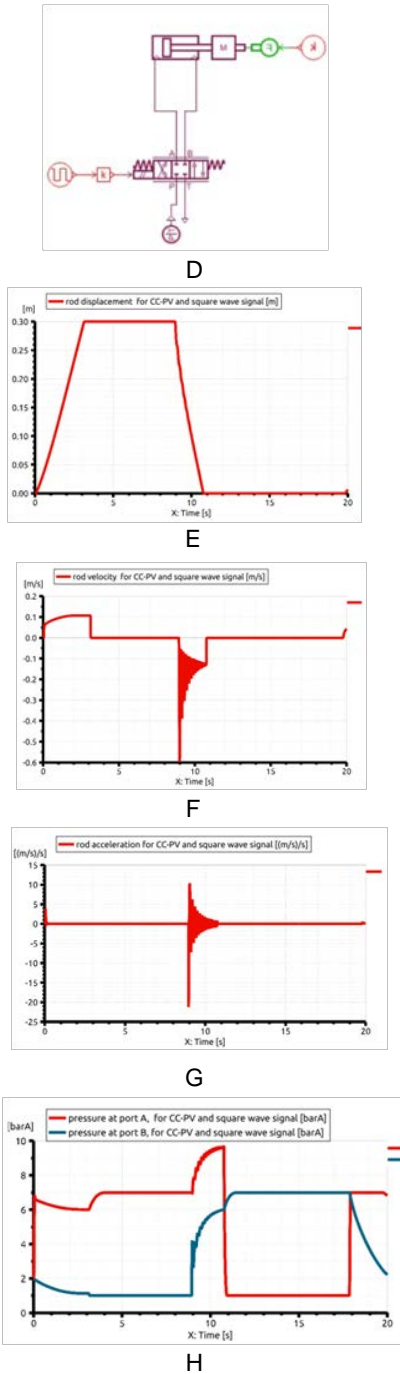


Fig. 6 3\$ && 39 645:

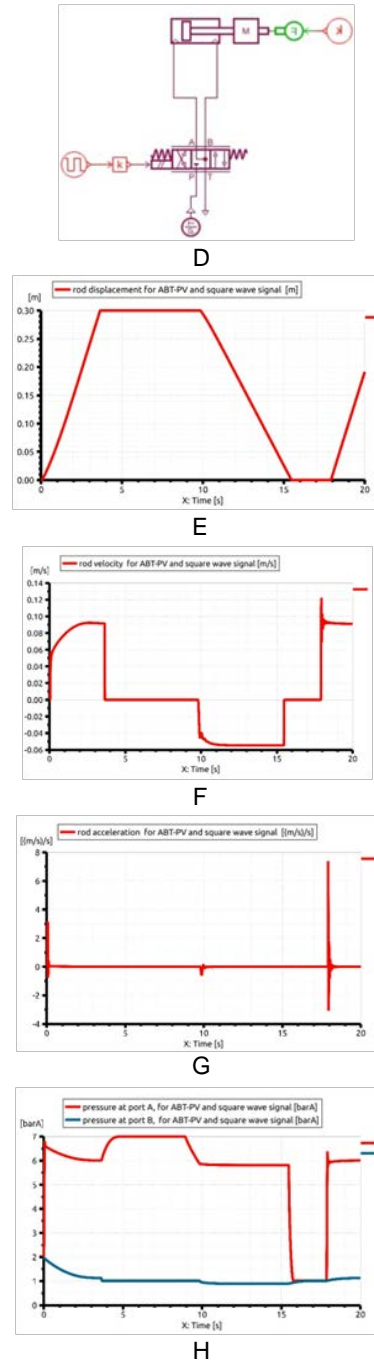


Fig. 7 3\$ \$%7 39 645:

,Q ILJXUHV DQG LV REVHUYHG WKH G\QDPLF EHV
 FRQWUROOHG E\ SURSRUWLRQDO YDOYH DW VTXDUH ZD

W L P H D S S H D U L Q W K H U R G P R Y H P H Q W , W L V R E V H U Y H G
 Z H L J K W) L J X U H H 7 R R E W D L Q W K L V E H K D Y L R X U W K
 F R P P D Q G E \ D V H P L V T X D U H Z D Y H V L J Q D O) L J X U H G

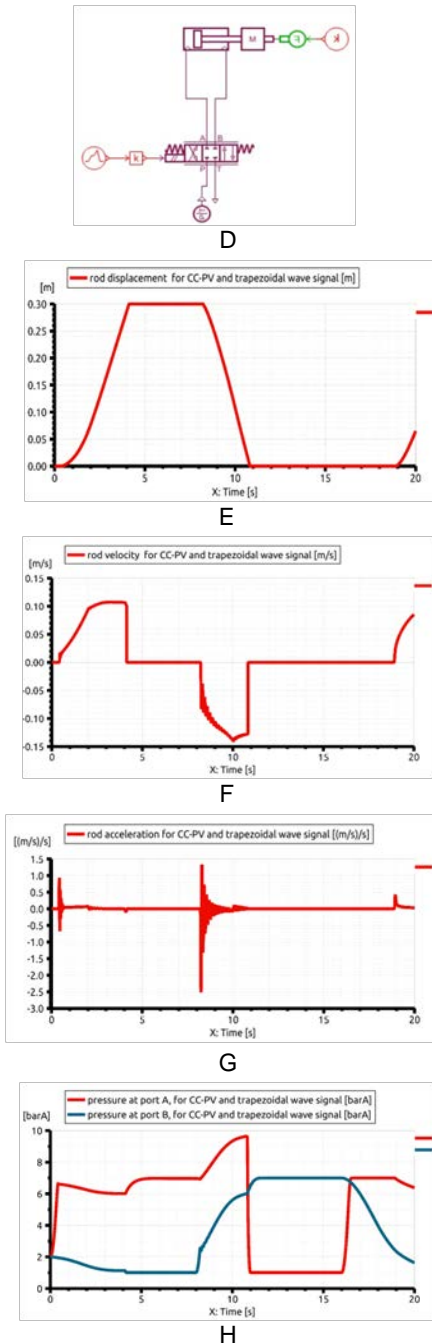


Fig. 8. 3\$ && 39 75\$3

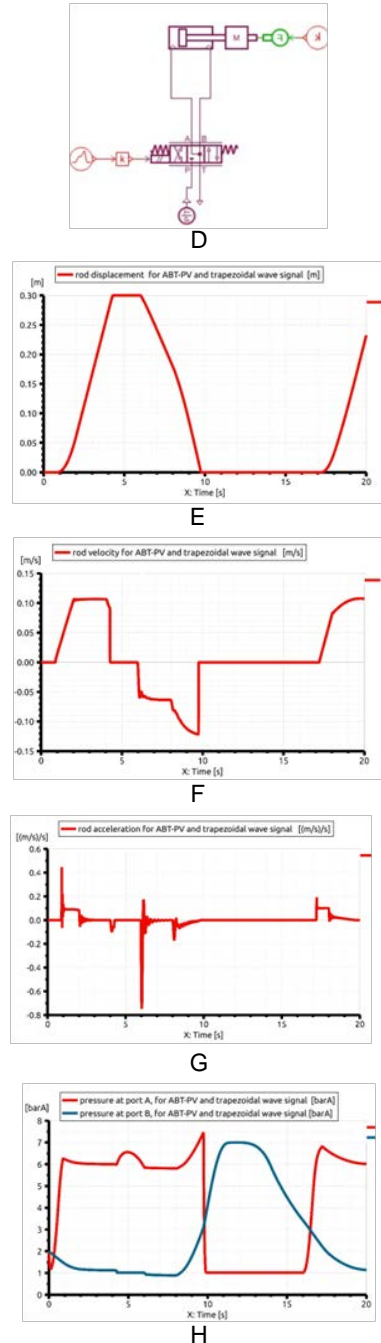


Fig. 9. 3\$ \$%7 39 75\$3

5 H J D U G L Q J W K H S U H V V X U H H Y R O X W L R Q L Q W K H F \ O L
 V D P H S D W W H U Q L V I R O O R Z L Q J Q R P D W W H U Z K D W W \ S H P
 V L J Q D O 7 K H S U H V V X U H U L V H V T X L F N O \ L Q W K H E L J J H U

WKH HQG RI WKH VWURNH WKH SUHVXUH GHFUHDVHV
RI WKH VPDOOHU FKDPEHU IRU D FRPSOHWH GXW\ F\FOH

&RQFOXVLRQV

7KH JRDO RI WKH SDSHU ZDV WKH VWXG\ RI WKH G\QD
RSHQ ORRS ZKHQ WKH FRQWURO YDOYH XVHG LV D
\$%7 FRQILJXUDWLRQ \$UH XVHG WKUHH W\SHV RI VLJQDO

7KH QXPULFDO VLPXODWLRQ UHVXOWV KDYH EHHQ
NQRZQ LQ WKH @LW\WKH W\PHH >GHOD\ RI PRYHPHQW PX
PDWKHPDWFDO PRGHO RI SQHXPDWLF DFWXDWRU WRR
WKDW XVLQJ SURSRUWLRQDO YDOYH WKH SQHXPDWLF
G\QDPLFV RI WKH SQHXPDWLF DFWXDWRU LQ RSHQ ORR
FDQ EH FKDQJHG RQO\ IURP WKH HOHFWULFDO VLJQDO
QRWLFHG LQ WKH FDVH RI WKH VTXDUH ZDYH VLJQDO V
ZKLFK DUH DOPRVW WKUHH W\PHV ELJJHU WKDQ RWKHU

7KH VWXG\ ZLOO EH IROORZHG E\ H[SHULPHQWV RQ
SDUDPHWHUV RI WKH H[SHULPHQWV ZLWK QXPULFDO VL

6SHFLDO WKDQV [KWWSV.5.0RIURRUDOSFRPH](#) VXSSRUW SURYLGH IR

5HIHUUHQFHV

< <LQJK 6SHHG 3QHXPDWLF 7KHRRU D,QG67WYFRQRQ
6SULQJHU

* &KDRKXL : &KHQJJDQJ7 ,QV6667 D

+ , \$OL 6 % % ORKG 1RRU 6 \$ 5% DVKZ RI 3+QHXDFU
\$FWXDWRUV ORGHO \$QVWDOO &RWRROQDO RI %DVLV
3

(5LFKHU < \$XULK]OXUIRUPDQFH 3QHXPDWLF)RUFH
1RQOLQH DU ODWK \$6DWRK DQDOR GHO\QDPLF 6\ VWHPV
DQG &RWRRO SS

, .ULYLWV * 3QHXPDWLF \$FWXDWLQJ 6\ VWHPV IRU
6WUXFWXUH DQG GUNLVVQ3UHV 7D\ORU DQG)UDQFLV :

1 9DVLQX ' 9DVLQX & &OLQLX 5 3XKDOVFKL
ZLWK 6LPFHQWHU \$PHVLP &5& 3UHV 7D\ORU DQG)U

0 *DODO 5DELH)OXLG 3RZHU (QJLQHHLQJ 0F*UDZ
< 7DVVD 7 :X , { 0RGROGHO LQJ DQG ,GHQWLILFDWL

\$FWXDWRUV FRQIHUHQFH SDSHU&0\$
[KWWSV_ZZZ_UHVHDFKJDWH_QHW_SXEOLFDWLRQ](#)

* \$ 0X]\ \$ 6 &DSRUDOL 3RVLWLRQLQJ V\ VWHP RI
SURSRUWLRQDO SUHVVURFHUHLQJ DWRW KH DOWK V:RUNV
(QJLQHHLQJ)RU)QXBG 3RZHU,0\$ 6mR 3DXOR 63 %
HFS

9 &RQVDQWLQ * %HOIRUWH 2 'RQWX 0ZKDL \$YU
,VV SS

0 6RUOL / *DVWDOGL (&RQDQDF DQGB\OLDW RHHSQ
DFWX DWRUODWLRQ 3UDFWLSFH DQG 7KHRU\