the s plane (PCT control-system configuration). If the Tustin approximation criteria of Sec. 22.8 are satisfied, the correlation between the two planes is very good. If the approximations are not valid, the analysis and design of the sampled-data control system should be done by the DIR technique.

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APPENDIX A

TABLE OF LAPLACE TRANSFORM PAIRS

$F(s)$	$f(t) \quad 0 \le t$
1. 1	$u_0(t)$ unit impulse at $t = 0$
2. $\frac{1}{s}$	1 or $u_{-1}(t)$ unit step starting at $t = 0$
3. $\frac{1}{s^2}$	$tu_{-1}(t)$ ramp function
4. $\frac{1}{s^n}$	$\frac{1}{(n-1)!}t^{n-1}$ n = positive integer
5. $\frac{1}{s}e^{-as}$	$u_{-1}(t-a)$ unit step starting at $t = a$
6. $\frac{1}{s}(1 - e^{-as})$	$u_{-1}(t) - u_{-1}(t-a)$ rectangular pulse
7. $\frac{1}{s+a}$	e^{-at} exponential decay
8. $\frac{1}{(s+a)^n}$	$\frac{1}{(n-1)!}t^{n-1}e^{-at}$ n = positive integer
9. $\frac{1}{s(s+a)}$	$\frac{1}{a}(1 - e^{-at})$
10. $\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab}\left(1 - \frac{b}{b-a}e^{-at} + \frac{a}{b-a}e^{-bt}\right)$

$F(s)$	$f(t) \quad 0 \le t$
11. $\dfrac{s+\alpha}{s(s+a)(s+b)}$	$\dfrac{1}{ab}\left[\alpha - \dfrac{b(\alpha-a)}{b-a}e^{-at} + \dfrac{a(\alpha-b)}{b-a}e^{-bt}\right]$
12. $\dfrac{1}{(s+a)(s+b)}$	$\dfrac{1}{b-a}(e^{-at} - e^{-bt})$
13. $\dfrac{s}{(s+a)(s+b)}$	$\dfrac{1}{a-b}(ae^{-at} - be^{-bt})$
14. $\dfrac{s+\alpha}{(s+a)(s+b)}$	$\dfrac{1}{b-a}[(\alpha-a)e^{-at} - (\alpha-b)e^{-bt}$
15. $\dfrac{1}{(s+a)(s+b)(s+c)}$	$\dfrac{e^{-at}}{(b-a)(c-a)} + \dfrac{e^{-bt}}{(c-b)(a-b)} + \dfrac{e^{-ct}}{(a-c)(b-c)}$
16. $\dfrac{s+\alpha}{(s+a)(s+b)(s+c)}$	$\dfrac{(\alpha-a)e^{-at}}{(b-a)(c-a)} + \dfrac{(\alpha-b)e^{-bt}}{(c-b)(a-b)} + \dfrac{(\alpha-c)e^{-ct}}{(a-c)(b-c)}$
17. $\dfrac{\omega}{s^2+\omega^2}$	$\sin \omega t$
18. $\dfrac{s}{s^2+\omega^2}$	$\cos \omega t$
19. $\dfrac{s+\alpha}{s^2+\omega^2}$	$\dfrac{\sqrt{\alpha^2+\omega^2}}{\omega}\sin(\omega t+\phi) \qquad \phi = \tan^{-1}\dfrac{\omega}{\alpha}$
20. $\dfrac{s\sin\theta + \omega\cos\theta}{s^2+\omega^2}$	$\sin(\omega t+\theta)$
21. $\dfrac{1}{s(s^2+\omega^2)}$	$\dfrac{1}{\omega^2}(1-\cos\omega t)$
22. $\dfrac{s+\alpha}{s(s^2+\omega^2)}$	$\dfrac{\alpha}{\omega^2} - \dfrac{\sqrt{\alpha^2+\omega^2}}{\omega^2}\cos(\omega t+\phi) \qquad \phi = \tan^{-1}\dfrac{\omega}{\alpha}$
23. $\dfrac{1}{(s+a)(s^2+\omega^2)}$	$\dfrac{e^{-at}}{a^2+\omega^2} + \dfrac{1}{\omega\sqrt{a^2+\omega^2}}\sin(\omega t-\phi) \qquad \phi = \tan^{-1}\dfrac{\omega}{a}$
24. $\dfrac{1}{(s+a)^2+b^2}$	$\dfrac{1}{b}e^{-at}\sin bt$
24a. $\dfrac{1}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\dfrac{1}{\omega_n\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\omega_n\sqrt{1-\zeta^2}\,t$
25. $\dfrac{s+a}{(s+a)^2+b^2}$	$e^{-at}\cos bt$

$F(s)$	$F(t) \quad 0 \le t$
26. $\dfrac{s+\alpha}{(s+a)^2+b^2}$	$\dfrac{\sqrt{(\alpha-a)^2+b^2}}{b}e^{-at}\sin(bt+\phi) \qquad \phi = \tan^{-1}\dfrac{b}{\alpha-a}$
27. $\dfrac{1}{s[(s+a)^2+b^2]}$	$\dfrac{1}{a^2+b^2} + \dfrac{1}{b\sqrt{a^2+b^2}}e^{-at}\sin(bt-\phi) \qquad \phi = \tan^{-1}\dfrac{b}{-a}$
27a. $\dfrac{1}{s(s^2+2\zeta\omega_n s+\omega_n^2)}$	$\dfrac{1}{\omega_n^2} - \dfrac{1}{\omega_n^2\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t+\phi)$ $\phi = \cos^{-1}\zeta$
28. $\dfrac{s+\alpha}{s[(s+a)^2+b^2]}$	$\dfrac{\alpha}{a^2+b^2} + \dfrac{1}{b}\sqrt{\dfrac{(\alpha-a)^2+b^2}{a^2+b^2}}\,e^{-at}\sin(bt+\phi)$ $\phi = \tan^{-1}\dfrac{b}{\alpha-a} - \tan^{-1}\dfrac{b}{-a}$
29. $\dfrac{1}{(s+c)[(s+a)^2+b^2]}$	$\dfrac{e^{-ct}}{(c-a)^2+b^2} + \dfrac{e^{-at}\sin(bt-\phi)}{b\sqrt{(c-a)^2+b^2}} \qquad \phi = \tan^{-1}\dfrac{b}{c-a}$
30. $\dfrac{1}{s(s+c)[(s+a)^2+b^2]}$	$\dfrac{1}{c(a^2+b^2)} - \dfrac{e^{-ct}}{c[(c-a)^2+b^2]}$ $+\dfrac{e^{-at}\sin(bt-\phi)}{b\sqrt{a^2+b^2}\sqrt{(c-a)^2+b^2}}$ $\phi = \tan^{-1}\dfrac{b}{-a} + \tan^{-1}\dfrac{b}{c-a}$
31. $\dfrac{s+\alpha}{s(s+c)[(s+a)^2+b^2]}$	$\dfrac{\alpha}{c(a^2+b^2)} + \dfrac{(c-\alpha)e^{-ct}}{c[(c-a)^2+b^2]}$ $+\dfrac{\sqrt{(\alpha-a)^2+b^2}}{b\sqrt{a^2+b^2}\sqrt{(c-a)^2+b^2}}e^{-at}\sin(bt+\phi)$ $\phi = \tan^{-1}\dfrac{b}{\alpha-a} - \tan^{-1}\dfrac{b}{-a} - \tan^{-1}\dfrac{b}{c-a}$
32. $\dfrac{1}{s^2(s+a)}$	$\dfrac{1}{a^2}(at-1+e^{-at})$
33. $\dfrac{1}{s(s+a)^2}$	$\dfrac{1}{a^2}(1-e^{-at}-ate^{-at})$
34. $\dfrac{s+\alpha}{s(s+a)^2}$	$\dfrac{1}{a^2}[\alpha - \alpha e^{-at} + a(a-\alpha)te^{-at}]$
35. $\dfrac{s^2+\alpha_1 s+\alpha_0}{s(s+a)(s+b)}$	$\dfrac{\alpha_0}{ab} + \dfrac{a^2-\alpha_1 a+\alpha_0}{a(a-b)}e^{-at} - \dfrac{b^2-\alpha_1 b+\alpha_0}{b(a-b)}e^{-bt}$

$F(s)$	$f(t) \quad 0 \le t$
36. $\dfrac{s^2 + \alpha_1 s + \alpha_0}{s\left[(s+a)^2 + b^2\right]}$	$\dfrac{\alpha_0}{c^2} + \dfrac{1}{bc}[(a^2 - b^2 - \alpha_1 a + \alpha_0)^2 + b^2(\alpha_1 - 2a)^2]^{1/2} e^{-at} \sin(bt + \phi)$ $\phi = \tan^{-1} \dfrac{b(\alpha_1 - 2a)}{a^2 - b^2 - \alpha_1 a + \alpha_0} - \tan^{-1} \dfrac{b}{-a}$ $c^2 = a^2 + b^2$
37. $\dfrac{1}{(s^2 + \omega^2)\left[(s+a)^2 + b^2\right]}$	$\dfrac{(1/\omega)\sin(\omega t + \phi_1) + (1/b)e^{-at}\sin(bt + \phi_2)}{\left[4a^2\omega^2 + (a^2 + b^2 - \omega^2)^2\right]^{1/2}}$ $\phi_1 = \tan^{-1} \dfrac{-2a\omega}{a^2 + b^2 - \omega^2} \qquad \phi_2 = \tan^{-1} \dfrac{2ab}{a^2 - b^2 + \omega^2}$
38. $\dfrac{s + \alpha}{(s^2 + \omega^2)\left[(s+a)^2 + b^2\right]}$	$\dfrac{1}{\omega}\left(\dfrac{\alpha^2 + \omega^2}{c}\right)^{1/2} \sin(\omega t + \phi_1) + \dfrac{1}{b}\left[\dfrac{(\alpha - a)^2 + b^2}{c}\right]^{1/2} e^{-at} \sin(bt + \phi_2)$ $c = (2a\omega)^2 + (a^2 + b^2 - \omega^2)^2$ $\phi_1 = \tan^{-1} \dfrac{\omega}{\alpha} - \tan^{-1} \dfrac{2a\omega}{a^2 + b^2 + \omega^2}$ $\phi_2 = \tan^{-1} \dfrac{b}{\alpha - a} + \tan^{-1} \dfrac{2ab}{a^2 - b^2 + \omega^2}$
39. $\dfrac{s + \alpha}{s^2\left[(s+a)^2 + b^2\right]}$	$\dfrac{1}{c}\left(\alpha t + 1 - \dfrac{2\alpha a}{c}\right) + \dfrac{\left[b^2 + (\alpha - a)^2\right]^{1/2}}{bc} e^{-at} \sin(bt + \phi)$ $c = a^2 + b^2$ $\phi = 2\tan^{-1}\left(\dfrac{b}{a}\right) + \tan^{-1} \dfrac{b}{\alpha - a}$
40. $\dfrac{s^2 + \alpha_1 s + \alpha_0}{s^2(s+a)(s+b)}$	$\dfrac{\alpha_1 + \alpha_0 t}{ab} - \dfrac{\alpha_0(a+b)}{(ab)^2} - \dfrac{1}{a-b}\left(1 - \dfrac{\alpha_1}{a} + \dfrac{\alpha_0}{a^2}\right)e^{-at} - \dfrac{1}{1-b}\left(1 - \dfrac{\alpha_1}{b} + \dfrac{\alpha_0}{b^2}\right)e^{-bt}$

APPENDIX B

INTERACTIVE COMPUTER-AIDED DESIGN (CAD) PROGRAMS FOR DIGITAL AND CONTINUOUS CONTROL-SYSTEM ANALYSIS AND SYNTHESIS

B.1 INTRODUCTION

Various CAD software packages[B1–B15] are available for the development of continuous- and discrete-time control systems. These packages can assist the control engineer in performing time-consuming calculations for both scalar and multivariable models. Some of the available CAD packages provide the user with an integrated set of design tools and perform a broad range of calculations applicable to control-system analysis and synthesis. The computer program called TOTAL[B9] (TOTAL-I) is presented in this appendix as an example of a specific