A general schlicht integral operator

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Abstract

Let $A$ be the class of analytic functions $f$ in the open complex unit disc $U = \{ z \in \mathbb{C} : |z| < 1 \}$, with $f(0) = 0, f'(0) = 1$ and $f(z)/z \neq 0$ in $U$. Let define the integral operator $I : A \rightarrow A$, $I(f) = F$, where:

$$ F(z) = \left[ (\alpha + \beta + 1) \int_0^z f^\alpha(u)g^\beta(u) \right]^{1/(\alpha+\beta+1)}, \quad z \in U $$

With suitable conditions on the constants $\alpha$ and $\beta$ and on the function $g \in A$, the author shows that $F$ is analytic and univalent (or schlicht) in $U$. Additional results are also obtained, such as a new generalization of Becker’s condition of univalence and improvements of some known results.

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1 Introduction

Let $U = \{ z \in \mathbb{C} : |z| < 1 \}$ be the complex unit disc and let $A$ be the class of analytic functions in $U$ of the form:

$$f(z) = z + a_n z^n + a_{n+1} z^{n+1} + \cdots$$

and with $f(z)/z \neq 0$ for all $z \in U$.

Univalence of complex functions is an important property, but, unfortunately, it is difficult, and in many cases impossible, to show directly that a certain complex function is univalent. For this reason, many authors found different types of sufficient conditions of univalence. One of these conditions of univalence is the well–known criterion of Ahlfors and Becker ([1] and [7]), which states that the function $f \in A$ is univalent if:

$$(1) \quad (1 - |z|^2) \left| \frac{zf''(z)}{f'(z)} \right| \leq 1$$

There are many generalizations of this criterion, such those obtained in [4], [5], [6] and [9]. In this paper, as an additional result, we will also obtain a new generalization of the above–mentioned univalence criterion. The principal result deals with finding sufficient conditions on the constants $\alpha$ and $\beta$ and on the function $g \in A$ so that the function:

$$(2) \quad F(z) = \left[ (\alpha + \beta + 1) \int_0^z f^\alpha(u)g^\beta(u)du \right]^{1/(\alpha+\beta+1)}, \quad z \in U$$

is univalent. The result improves also former results obtained in [3], [4], [5], [6] and [7].
2 Preliminaries

For proving our principal result we will need the following definitions and lemma:

Definition 1. If \( f \) and \( g \) are analytic functions in \( U \) and \( g \) is univalent, then we say that \( f \) is subordinate to \( g \), written \( f \prec g \) or \( f(z) \prec g(z) \) if \( f(0) = g(0) \) and \( f(U) \subset g(U) \).

Definition 2. A function \( L(z, t) \), \( z \in U, t \geq 0 \) is called a L"owner chain or a subordination chain if:

(i) \( L(\cdot, t) \) is analytic and univalent in \( U \) for all \( t \geq 0 \).
(ii) \( L(z, \cdot) \) is continuously differentiable in \([0, \infty)\) for all \( t \geq 0 \).
(iii) \( L(z, s) \prec L(z, t) \) for all real \( s \) and \( t \) with \( 0 \leq s < t \).

Let \( 0 < r \leq 1 \). We denote by \( U_r \) the set: \( U_r = \{ z \in \mathbb{C} : |z| < r \} \).

Lemma 1. ([8], [9]) Let \( 0 < r_0 \leq 1, t \geq 0 \) and \( a_1(t) \in \mathbb{C} \setminus \{0\} \). Let:

\[
L(z, t) = a_1(t) z + a_2(t) z^2 + \cdots
\]

be analytic in \( U_{r_0} \) for all \( t \geq 0 \), locally absolutely continuous in \([0, \infty)\) locally uniform with respect to \( U_{r_0} \). For almost all \( t \geq 0 \) suppose that:

\[
(3) \quad z \frac{\partial L(z, t)}{\partial z} = p(z, t) \frac{\partial L(z, t)}{\partial t}, \quad z \in U_{r_0}
\]

where \( p(z, t) \) is analytic in the unit disc \( U \) and \( \text{Re} p(z) > 0 \) in \( U \) for all \( t \geq 0 \). If:

\[
\lim_{t \to \infty} |a_1(t)| = \infty
\]
and \{L(z,t)/a_1(t)\} forms a normal family in \(U_{\alpha t}\), then, for each \(t \geq 0\), \(L(z,t)\) has an analytic and univalent extension to the whole unit disc \(U\) and is a Löwner chain.

Lemma 1 is a variant of the well–known theorem of Pommerenke ([8]) and it’s proof can be found in [9].

3 Principal result

Let \(B\) be the class of analytic functions \(p\) in \(U\) with \(p(0) = 1\) and \(p(z) \neq 0\) for all \(z \in U\).

**Theorem 1.** Let \(f, g \in A, p \in B\) and \(\alpha, \beta, \gamma\) and \(\delta\) complex numbers satisfying:

\[
\text{(4)} \quad \text{Re} \frac{\gamma}{\alpha + \beta + 1} > \frac{1}{2}
\]

\[
\text{(5)} \quad \text{Re}(\alpha + \beta + 1) > 0
\]

\[
\text{(6)} \quad \text{Re} \gamma > 0
\]

\[
\text{(7)} \quad \left| \frac{\delta + 1}{\gamma p(z)} - 1 \right| < 1, \quad z \in U
\]

\[
\text{(8)} \quad \left| \frac{\delta + 1}{\alpha + \beta + 1} - 1 \right| < 1
\]

and, for all \(z \in U\):

\[
\text{(9)} \quad \left| \frac{1 - \gamma}{\gamma} + \frac{1 + \delta - p(\bar{z})}{\gamma p(\bar{z})} |z|^2 + \frac{1 - z^{2\gamma}}{\gamma} \left[ \frac{zf'(\bar{z})}{f(\bar{z})} + \frac{\beta zg'(\bar{z})}{g(\bar{z})} + \frac{zp'(\bar{z})}{p(\bar{z})} \right] \right| \leq 1
\]

Then, the function \(F\) defined by (2) is analytic and univalent in \(U\).
Prooof. Let:

\[ h(u) = \left[ \frac{f(u)}{u} \right]^\alpha \left[ \frac{g(u)}{u} \right]^\beta \]

where the powers are considered with their principal branches. The function \( h \) does not vanish in \( U \) because \( f \) and \( g \) are in \( A \). Let define now the function:

\[ h_1(z, t) = \frac{\alpha + \beta + 1}{(e^{-tz})^{\alpha + \beta + 1}} \int_0^{e^{-tz}} h(u)u^{\alpha + \beta}du = 1 + b_1z + \cdots \]

where \( t \geq 0 \) and \( z \in U \). We consider now the power development of \( h \):

\[ h(u) = 1 + \sum_{n=1}^{\infty} c_n u^n, \ u \in U. \]

We denote:

\[ \phi(w) = \frac{\alpha + \beta + 1}{w^{\alpha + \beta + 1}} \int_0^w h(u)u^{\alpha + \beta}du = 1 + \sum_{n=1}^{\infty} c_n \frac{\alpha + \beta + 1}{n + \alpha + \beta + 1} w^n. \]

From (5) we have that \( \text{Re}(\alpha + \beta + 1) > 0 \) and, consequently:

\( \text{Re}(\alpha + \beta + 1) > -n/2 \) for all \( n \in \mathbb{N} \). It follows immediately that:

\[ \text{Re} \left( \frac{n}{n + 2(\alpha + \beta + 1)} \right) > 0, \ n \in \mathbb{N} \]

and hence:

\[ \left| \frac{\alpha + \beta + 1}{n + \alpha + \beta + 1} \right| < 1. \]

Taking into account that \( h \) is analytic in \( U \), we deduce that:

\[ 1 + \sum_{n=1}^{\infty} c_n \frac{\alpha + \beta + 1}{n + \alpha + \beta + 1} w^n \]

converges locally uniformly in \( U \), and, thus, \( \phi \) is analytic in \( U \). Because for every \( t \geq 0 \) and for every \( z \in U \) we have that \( e^{-tz} \in U \) we deduce that \( \phi(e^{-tz}) = h_1(z, t) \) is analytic in \( U \) for all \( t \geq 0 \). Let now:

\[ m = \frac{\alpha + \beta + 1}{\delta + 1} \]
\[ h_2(z, t) = p(e^{-t}z)h(e^{-t}z), \ z \in U, \ t \geq 0 \]

\[ h_3(z, t) = h_1(z, t) + m(e^{2\gamma t} - 1)h_2(z, t), \ z \in U, \ t \geq 0. \]

Suppose now that \( h_3(0, t_1) = 0 \) for a certain positive real number \( t_1 \), that is \( 1 + m(e^{2\gamma t_1} - 1) = 0 \), or:

\[ e^{2\gamma t_1} = \frac{m - 1}{m} = \frac{\alpha + \beta - \delta}{\alpha + \beta + 1}. \]

From (6) we have that \( |e^{2\gamma t_1}| = e^{2t_1 \text{Re}\gamma} \geq 1 \) and from (8) we deduce that \( \left| \frac{\alpha + \beta - \delta}{\alpha + \beta + 1} \right| < 1 \). It follows immediately that (10) is false and then, we have:

\[ h_3(0, t) \neq 0 \text{ for all } t \geq 0 \]

Let now suppose that for all \( r \) with \( 0 < r \leq 1 \) it exists at least one \( t_r \geq 0 \) so that \( h_3(z, t_r) \) has at least one zero in \( U_r = \{z \in \mathbb{C} : |z| < r\} \). We choose \( r = 1, 1/2, 1/3, \ldots \) and form a sequence \( (t_n)_{n \in \mathbb{N}} \) so that \( h_3(z, t_n) \) has at least one zero in \( U_{1/n} \).

If \( (t_n)_{n \in \mathbb{N}} \) is bounded, we can find a subsequence \( (t_{n_k})_{k \in \mathbb{N}} \) of \( (t_n)_{n \in \mathbb{N}} \) that converges to \( \tau_0 \geq 0 \). Because \( h_3 \) is continuously with respect to \( t \) we obtain:

\[ \lim_{k \to \infty} h_3(z, t_{n_k}) = h_3(z, \tau_0) \text{ for all } z \in U. \]

But in this case \( h_2(\cdot, \tau_0) \) has at least one zero in every disc \( U_{1/n_k} \). If we let now \( k \to \infty \) we deduce that \( h_3(0, \tau_0) = 0 \), which contradicts (11).

If the sequence \( (t_n)_{n \in \mathbb{N}} \) is unbounded we can consider, without loss of generality, that \( \lim_{n \to \infty} t_n = \infty \). We have now:

\[ h_3(z, t) = h_1(z, t) + m(e^{2\gamma t} - 1)h_2(z, t) = \phi(e^{-t}z) + m(e^{2\gamma t} - 1)h_2(z, t) \]
Because $\phi(0) = 1$ we deduce that $M = \max_{z \in \overline{U}} |\phi(e^{-t}z)| > 0$. Because $p(0)h(0) = 1$, there exists $r_1 \in (0, 1]$ so that $p(w)h(w) \neq 0$ in $\overline{U}_{r_1}$. Then, $h_2(w, t) = p(e^{-t}z)h(e^{-t}z)$ do not vanish in $\overline{U}_{r_1}$ for every $t \geq 0$ and, thus, we have: $K = \min_{w \in \overline{U}_{r_1}} |h_2(w, t)| > 0$. From (5) we deduce that $m \neq 0$ and thus, $|m| > 0$. It follows immediately that:

$$\lim_{t \to \infty} |1 - e^{2\gamma t}| = \lim_{t \to \infty} e^{2t \text{Re} \gamma} \sqrt{e^{-4t \text{Re} \gamma} - 2e^{-2t \text{Re} \gamma} \cos 2t \text{Im} \gamma + 1} = \infty$$

because $\text{Re} \gamma > 0$.

Hence, for sufficiently large $t$ we have:

$$|m| |1 - e^{2\gamma t}| |h_2(z, t)| > |m| |1 - e^{2\gamma t}| K > M + 1 > |\phi(e^{-t}z) + 1|$$

(12)

In the same time we have:

$$|h_3(z, t)| = |h_1(z, t) - m \left(1 - e^{2\gamma t}\right) h_2(z, t)| \geq$$

$$\geq \left||h_1(z, t)| - |m| |1 - e^{2\gamma t}| |h_2(z, t)|\right|$$

From (12) it follows immediately that $|h_3(z, t)| > 1$ for all $z \in U_{r_1}$ and for sufficiently large $t$. Thus, it exists $N \in \mathbb{N}$ so that $h_3(\cdot, t_n)$ does not vanish in $U_{r_1}$ for all $n > N$. For $n \in [0, N]$ we have that $h_3(z, t_n)$ does not vanish in $U_{r_2}$ where:

$$r_2 = \min\{r_n : h_3(z, t) \neq 0, z \in U_{r_n}, t \geq 0, n \in [0, N]\}.$$ 

If we let now $r_0 = \min\{r_1, r_2\}$ we have that $h_3(\cdot, t_n)$ does not vanish in $U_{r_0}$ for every $n \in \mathbb{N}$. It follows that the supposition of the nonexistence of a positive real number $r_0 < 1$ with the property that $h_3(z, t) \neq 0$ for all $t \geq 0$ and all $z \in U_{r_0}$ is false. Hence, we can choose $r_0 \in (0, 1]$ so that $h_3(z, t) \neq 0$
for all \( t \geq 0 \) and all \( z \in U_{r_0} \).

Let \( h_4(z, t) \) be the uniform branch of \([h_3(z, t)]^{1/(\alpha + \beta + 1)}\) which takes the value 
\([1 + m(e^{2\gamma t} - 1)]^{1/(\alpha + \beta + 1)}\) at the origin. Let us define:

\[
L(z, t) = e^{-t}zh_4(z, t)
\]

which is analytic for all \( t \geq 0 \). If \( L(z, t) = a_1(t)z + a_2(z)z^2 + \cdots \), it is clear
that \( L(0, t) = 0 \) for every \( t \geq 0 \) and:

\[
a_1(t) = e^{-t} \left[ 1 + m(e^{2\gamma t} - 1) \right]^{1/(\alpha + \beta + 1)}.
\]

From the above written equations we can formally write:

\[
L(z, t) = [L_1(z, t)]^{1/(\alpha + \beta + 1)} = [(\alpha + \beta + 1) \int_0^{e^{-t}z} f^\alpha(u)g^\beta(u)du +
+m(e^{2\gamma t} - 1)e^{-t}zf^\alpha(e^{-t}z)g^\beta(e^{-t}z)p(e^{-t}z)]^{1/(\alpha + \beta + 1)}.
\]

By simple calculations we obtain:

\[
a_1(t) = (c + 1)^{-1/\alpha + \beta + 1}e^{\frac{2\gamma t - \alpha - \beta - 1}{\alpha + \beta + 1}} \left[ \alpha + \beta + 1 - (\alpha + \beta - c)e^{-2\gamma t} \right]^{1/\alpha + \beta + 1}.
\]

Thus, \( e^ta_1(t) = h_4(0, t) = [h_3(0, t)]^{1/(\alpha + \beta + 1)} \) with the chosen uniform
branch. Because \( h_3(\cdot, t) \) does not vanish in \( U_{r_0} \) for all \( t \geq 0 \), we obtain
that \( a_1(t) \neq 0 \) for every \( t \geq 0 \). If we let \( t \to \infty \), from (4) and (6) we easily
obtain:

\[
\lim_{t \to \infty} |a_1(t)| = \infty.
\]

Because \( h_4(\cdot, t) \) is analytic in \( U_{r_0} \) for every \( t \geq 0 \), we deduce that \( L(z, t) =
e^{-t}zh_4(z, t) \) is also analytic in \( U_{r_0} \) for all \( t \geq 0 \).

The family \( \{ L(z, t)/a_1(t) \}_{t \geq 0} \) consists of analytic functions in \( U_{r_0} \). Hence, this family is uniformly bounded
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in \( U_{r_1} \), where \( 0 < r_1 \leq r_0 \). By applying Montel’s theorem we have that \( \{ L(z, t)/a_1(t) \} \) forms a normal family in \( U_{r_1} \). Let denote:

\[
J(z, t) = m(e^{2\gamma t} - 1) \left[ \alpha \frac{e^{t}zf'(e^{t}z)}{f(e^{t}z)} + \beta \frac{e^{t}zp'(e^{t}z)}{p(e^{t}z)} \right] p(e^{t}z)
\]

From (14) we obtain:

\[
\frac{\partial L(z, t)}{\partial t} = \frac{1}{\alpha + \beta + 1} \left[ L_1(z, t) \right]^{\frac{\alpha + \beta}{\alpha + \beta + 1}} e^{-t} z f^\alpha(e^{-t}z) g^\beta(e^{-t}z) \cdot \cdot \left[ 2\gamma me^{2\gamma t} p(e^{-t}z) - m(e^{2\gamma t} - 1)p(e^{-t}z) - \alpha - \beta - 1 - J(z, t) \right]
\]

It is clear that \( \partial L(z, t)/\partial t \) is analytic in \( U_{r_2} \), where \( 0 < r_2 \leq r_1 \). Consequently, \( L(z, t) \) is locally absolutely continuous and we have also:

\[
\frac{\partial L(z, t)}{\partial z} = \frac{1}{\alpha + \beta + 1} \left[ L_1(z, t) \right]^{\frac{\alpha + \beta}{\alpha + \beta + 1}} e^{-t} z f^\alpha(e^{-t}z) g^\beta(e^{-t}z) \cdot \cdot \left[ m(e^{2\gamma t} - 1)p(e^{-t}z) + \alpha + \beta + 1 + J(z, t) \right]
\]

Let:

\[
p_1(z, t) = \frac{z\partial L(z, t)/\partial z}{\partial L(z, t)/\partial t} = \frac{m(e^{2\gamma t} - 1)p(e^{-t}z) + \alpha + \beta + 1 + J(z, t)}{(2\gamma - 1)me^{2\gamma t}p(e^{-t}z) + mp(e^{-t}z)}
\]

Consider now the function:

\[
w(z, t) = \frac{p_1(z, t) - 1}{p_1(z, t) + 1}
\]

Further calculations show that:

\[
w(z, t) = \frac{m(1 - \gamma)e^{2\gamma t}p(e^{-t}z) - mp(e^{-t}z) + \alpha + \beta + 1 + J(z, t)}{\gamma me^{2\gamma t}p(e^{-t}z)}
\]

It is clear that \( w(\cdot, t) \) is analytic in \( U_{r_2} \) for all \( t \geq 0 \). Hence, \( w(\cdot, t) \) has an analytic extension \( \bar{w}(\cdot, t) \).
Let now $t = 0$. Taking into account that $m = (\alpha + \beta + 1)/(\delta + 1)$, we easily obtain from (15):

$$\tilde{w}(z, 0) = -1 + \frac{c + 1}{\gamma p(z)}$$

and from (7) it follows immediately that $|\tilde{w}(z, 0)| < 1$.

Let now $t > 0$. We observe that $\tilde{w}(·, t)$ is analytic in $\overline{U} = \{z \in \mathbb{C} : |z| \leq 1\}$ because if $t \geq 0$, for every $z \in \overline{U}$ we have that $e^{-t}z \in U$. In this case we have:

$$|\tilde{w}(z, t)| = \max_{z \in \overline{U}} |\tilde{w}(z, t)| = \max_{|z| = 1} |\tilde{w}(z, t)| = |\tilde{w}(e^{i\theta}, t)|$$

with $\theta \in \mathbb{R}$. Let $v = e^{-t}e^{i\theta} \in U$. After simple calculations we obtain:

$$\tilde{w}(e^{i\theta}, t) = \frac{1 - \gamma}{\gamma} + \frac{\alpha + \beta + 1 - mp(v)}{\gamma mp(v)}|v|^{2\gamma} +$$

$$+ \frac{1 - |v|^{2\gamma}}{\gamma} \left[ \frac{vf'(v)}{f(v)} + \beta \frac{vg'(v)}{g(v)} + \frac{vp'(v)}{p(v)} \right]$$

But:

$$\frac{\alpha + \beta + 1 - mp(v)}{\gamma mp(v)} = \frac{\delta + 1 - p(v)}{\gamma p(v)}$$

and from (9) we deduce that $|\tilde{w}(e^{i\theta}, t)| \leq 1$ and hence, $|\tilde{w}(z, t)| < 1$ in $U$ for all $t \geq 0$. From the definition of $w$ and $\tilde{w}$ we deduce that $p_1(·, t)$ has an analytic extension $\tilde{p}_1(·, t)$ to the whole disc $U$ for all $t \geq 0$ and $\text{Re} \tilde{p}_1(z, t) > 0$ in $U$ for all $t \geq 0$. By applying Lemma 1 we obtain that $L(z, t)$ is a subordination chain and thus, $L(z, 0) = F(z)$ is analytic and univalent in $U$ and the proof of the theorem is complete.

**Remark 1.** We can write a variant of Theorem 1 with $\gamma \in \mathbb{R}$. In this case, condition (8) can be replaced by:

$$1 - \frac{\delta + 1}{\alpha + \beta + 1} \notin [1, \infty).$$
However, condition (8) was necessary only for showing that \( h_2(0,t) \neq 0 \) for all \( t \geq 0 \). But if \( \gamma \in \mathbb{R} \) then \( h_2(0,t) = 0 \) is equivalent to \( e^{2\gamma t} = (m - 1)/m \in \mathbb{R} \). But this last equality is impossible because \( e^{2\gamma t} > 1 \) and \( (m - 1)/m \notin [1, \infty) \).

4 Some particular cases

If we let in Theorem 1 \( \gamma = 1 \) and \( p(z) = 1 \) for all \( z \in U \), then we obtain, using Remark 1 also, the following result:

**Corollary 1.** If \( f, g \in A \) and \( \alpha, \beta \) and \( \delta \) are complex numbers satisfying:

(17) \(|\alpha + \beta| < 1\)

(18) \(|\delta| < 1\)

(19) \(1 - (\delta + 1)/(\alpha + \beta + 1) \notin [1, \infty)\)

(20) \[|c|z|^2 + (1 - |z|^2) \left[ \frac{zf'(z)}{f(z)} + \beta \frac{zg'(z)}{g(z)} \right] \leq 1, \ z \in U\]

then the function \( F \) defined in (2) is analytic and univalent in \( U \).

If in Corollary 1 we let \( \delta = \alpha + \beta \) we obtain Theorem 1 from [5] and if we let additionally \( g(z) = z \) for all \( z \in U \) we obtain Theorem 1 from [4]. For \( \beta = -1 \) in this last theorem we obtain Theorem 1 from [3].

From Theorem 1 we can obtain many other results by choosing properly the constants. An interesting example can be obtained if we let \( \alpha + \beta = \omega \), \( p(z) = 1 \) and \( g(z) = f(z)[f'(z)]^{1/\beta} \) for all \( z \in U \) in Theorem 1. For the power we choose the principal branch and obtain:
Corollary 2. If \( f \in A \) and \( \gamma, \delta \) and \( \omega \) are complex numbers satisfying:

\[
(21) \quad \Re \frac{2\gamma}{\omega + 1} > 1
\]

\[
(22) \quad \Re \gamma > 0, \quad \frac{\delta + 1}{\gamma} - 1 < 1, \quad \Re \omega < -1
\]

\[
(23) \quad \left| \frac{\delta + 1}{\omega + 1} - 1 \right| < 1
\]

and for all \( z \in U \):

\[
(24) \quad \left| \frac{1 - \gamma - \delta|z|^{2\gamma} + \omega(1 - |z|^{2\gamma})zf'(z)}{\gamma f(z)} + \frac{1 - |z|^{2\gamma}zf''(z)}{\gamma f'(z)} \right| \leq 1
\]

then \( f \) is univalent in \( U \).

If we let in Corollary 2 \( \gamma = 1 \) and use also Remark 1 we obtain a generalization of the well–known criterion of univalence of L.V.Ahlfors and J.Becker ( [1], [2] ), given in (1):

Corollary 3. If \( f \in A, \delta \) and \( \omega \in \mathbb{C} \) satisfy:

\[
(25) \quad |\delta| < 1
\]

\[
(26) \quad |\omega| < 1
\]

\[
(27) \quad \frac{\omega - \delta}{\delta + 1} \notin [1, \infty)
\]

\[
(28) \quad \left| \delta|z|^2 + \omega(1 - |z|^2)zf'(z) + (1 - |z|^2)zf''(z) \right| \leq 1, \; z \in U
\]

then \( f \) is univalent in \( U \).
For \( \delta = \omega = 0 \) we obtain from Corollary 3 the criterion of univalence of Ahlfors and Becker.

For \( \delta = \omega = (1 - \alpha)/\alpha \), conditions (25) and (26) are equivalent to: \( \text{Re} \alpha > 1/2 \) and we obtain the result from [6].

If in Corollary 2 we let \( \omega = 0 \) and \( \gamma = (m + 1)/2 \), \( m \in \mathbb{R} \) we obtain the result from [7].

References


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